Vol. XXII.—No. 133] [June, 1931.

THE

MINERALOGICAL MAGAZINE

AND

Journal of

The Mineralogical Society

(*INSTITUTED FEBRUARY 3, 1876.*)

WITH A SEPARATELY-PAGED APPENDIX OF

MINERALOGICAL ABSTRACTS

EDITED BY L. J. SPENCER, F.R.S.

ABSTRACTORS

F. N. ASHCROFT.
F. A. BANNISTER.
H. E. BUCKLEY.
P. N. CHIRVINSKY.
T. CROOK.
A. F. HALLIMOND.
M. H. HEY.
HAROLD HILTON.
E. D. MOUNTAIN.
A. L. PARSONS.
G. T. PRIOR.
W. A. RICHARDSON.
S. J. SHAND.
F. SLAVÍK.
W. CAMPBELL SMITH.
L. J. SPENCER.
K. ZIMÁNYI.
V. ZSIVNY.

LONDON:
HUMPHREY MILFORD, OXFORD UNIVERSITY PRESS,
AMEN HOUSE, WARWICK SQUARE, E.C. 4.

1931.

Price 6s. net.
Annual Subscription for four numbers, Post free 20s.

MINERALOGICAL SOCIETY

Officers and Council for 1930–31.

PRESIDENT.

Sir JOHN S. FLETT, K.B.E., M.A., LL.D., D.Sc., F.R.S.

PAST-PRESIDENTS.

Sir HENRY A. MIERS, M.A., D.Sc., LL.D., F.R.S. (1904–09).

A. E. H. TUTTON, M.A., D.Sc., F.R.S. (1912–15).

W. BARLOW, F.R.S. (1915–18).

Prof. A. HUTCHINSON, O.B.E., M.A., Ph.D., F.R.S. (1921–24).

Prof. W. W. WATTS, M.A., M.Sc., Sc.D., LL.D., F.R.S. (1924–27).

G. T. PRIOR, M.A., D.Sc., F.R.S. (1927–30).

VICE-PRESIDENTS.

G. F. HERBERT SMITH, M.A., D.Sc., F.G.S., F.R.A.S.

Prof. C. GILBERT CULLIS, D.Sc., F.G.S.

TREASURER.

F. N. ASHCROFT, M.A., F.G.S., F.C.S., 1 *Egerton Gardens, South Kensington, London, S.W.* 3.

GENERAL SECRETARY.

W. CAMPBELL SMITH, M.C., T.D., M.A., F.G.S., *British Museum of Natural History, South Kensington, London, S.W.* 7.

FOREIGN SECRETARY.

Prof. A. HUTCHINSON, O.B.E., M.A., Ph.D., F.R.S.

EDITOR OF THE JOURNAL.

L. J. SPENCER, M.A., Sc.D., F.R.S., *British Museum of Natural History, South Kensington, London, S.W.* 7.

TRUSTEES.

F. N. ASHCROFT, M.A., F.G.S., F.C.S.

Sir HENRY A. MIERS, M.A., D.Sc., LL.D., F.R.S.

ORDINARY MEMBERS OF COUNCIL.

Col. N. T. BELAIEW, C.B., F.C.S.

Prof. W. L. BRAGG, O.B.E., M.A., F.R.S.

A. BRAMMALL, Ph.D., M.Sc., F.G.S.

H. COLLINGRIDGE, B.Sc., F.G.S.

G. M. DAVIES, M.Sc., F.G.S.

HENRY DEWEY, F.G.S.

Prof. W. G. FEARNSIDES, M.A., F.G.S.

A. F. HALLIMOND, M.A., F.G.S.

F. H. HATCH, O.B.E., Ph.D., F.G.S.

Prof. ARTHUR HOLMES, D.Sc., F.G.S.

Sir ALBERT E. KITSON, C.M.G., C.B.E., F.G.S.

Miss M. W. PORTER, B.Sc.

LIBRARIAN.

Miss J. M. SWEET, B.Sc., *British Museum of Natural History. South Kensington, London, S.W.* 7 (to which address all publications intended for the Library of the Society should be forwarded).

Bankers.—Messrs. Coutts & Co., 15 *Lombard Street, London, E.C.* 3.

THE MINERALOGICAL MAGAZINE
AND
JOURNAL OF
THE MINERALOGICAL SOCIETY

No. 133. June, 1931. Vol. XXII.

The Mbosi meteoric iron, Tanganyika Territory.

By D. R. Grantham, Ph.D., A.R.S.M.
and Frank Oates, B.Sc., A.R.S.M., A.I.C.
Geological Survey of Tanganyika Territory.

(With plates XIX and XX.)

[Read March 17, 1931; communicated, with a note, by L. J. Spencer, F.R.S.]

Discovery and General Description (By D. R. Grantham).

THE meteorite is situated on the western slope of Marengi Hill, about 150 yards from the top of the hill and close to the boundary of Mr. Jennes's farm. This place is 10 miles south-east of the Mbosi mission station in Rungwe (formerly Langenburg) district. The latitude and longitude are approximately 9° 7′ S., 33° 4′ E. The locality lies between Lakes Tanganyika and Nyasa, south of Lake Rukwa, and about 23 miles from the border of Northern Rhodesia.

The country-rocks are gneisses with marked parallel banding, containing much felspar and penetrated by pegmatite stringers. The view that these rocks are of sedimentary origin is strengthened by the presence of a dark quartzitic gneiss with occasional streaks of limonite. A fresh, coarse-grained quartz-dolerite crosses the top of the hill.

The meteorite lies exposed for some 2 feet above the surface of the ground. It was buried 2 or 3 feet deep in a red loamy quartz rubble, which is covered by a few inches of soil. Beneath the mass is about a foot of rubble overlying the disintegrated gneiss. The lie

of the mass is very similar to that of a rock boulder which has travelled some distance by the 'run of the hill'. There are no signs of a crater or of the impact of a falling body, nor of any charring. When visited by the writer in December 1930 the ground had been excavated on one side of the mass.

The mass was discovered in October 1930 by Mr. W. H. Nott, a land surveyor of Johannesburg, who was erecting a triangulation beacon near by. He ordered a native assistant to go near the spot, but the native refused, explaining that there was a sacred stone

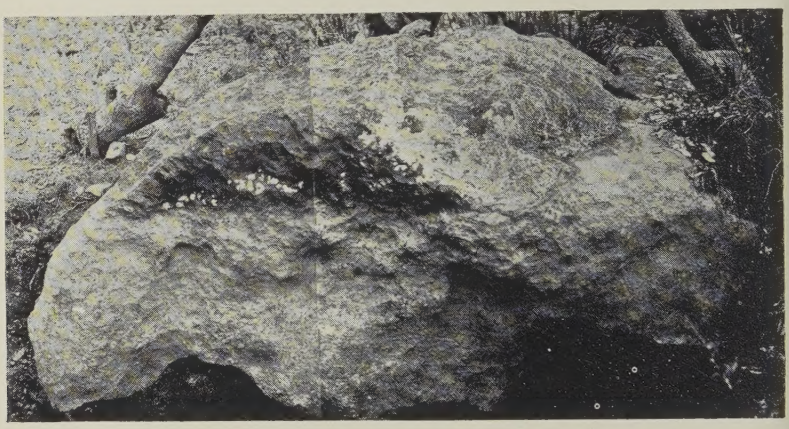


Fig. 1. The Mbosi meteorite; side view as seen in the excavation. (Much reduced: length 10 feet.)

which must not be approached. On making a search himself, Mr. Nott found the mass of iron. He promptly pegged the area as a base metal claim, and it was with his permission that samples were taken by the officers of the Geological Survey.

In addition to the saw cuts and chisel marks made by Europeans in attempts to secure specimens, the mass shows a few ancient tool marks. The local natives when questioned denied any knowledge of the mass, but their demeanour did not carry conviction. They certainly had some rites in connexion with it, but the exact nature of these could not be found out. In view of the lie of the meteorite there could scarcely be any legend of its fall, and the natives must have been attracted to it as being an unusual object.

Scattered through the rubble several feet from the mass are scraps up to an inch square and $\frac{1}{4}$-inch thick of a black nickeliferous iron

oxide. These no doubt are fragments of scale detached from the mass during its travel downhill.

As far as can be seen from the present exposure, the meteorite is roughly wedge-shaped, about 10 feet long, 3 feet wide, and 4 feet

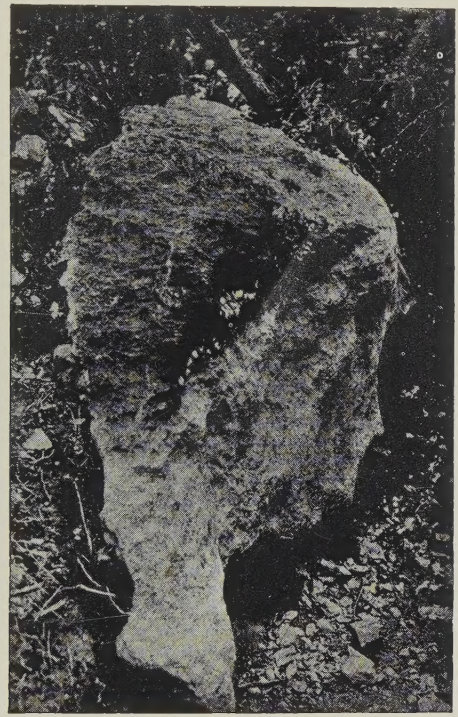


Fig. 2. The Mbosi meteorite viewed from the left end of fig. 1. (Much reduced.)

deep. It is lying on one of the triangular sides of the wedge and pointing nearly south-west. From the measurements of the exposed portion the weight of the mass is calculated to be from 12 to 15 tons, but it is possible that there may be some part still buried in the ground.

The hardness of the iron is comparable with that of hammer-steel. The oxidized skin is still harder as it cannot be cut with a hacksaw. After ten hours' continuous sawing by members of the party in relays a piece of the iron was detached with a cut surface of 5·3 square inches. During the sawing it was noticed that the edges of

the cut were slightly magnetic, as they attracted the fine sawdust. Neither the meteorite as a whole nor the piece detached appeared to be appreciably magnetized.

The weathering of the iron is evidently exceedingly slow, it being almost free from rust. A cut surface that had been exposed to the weather for some weeks showed only a slight tarnish. The fine sawdust was only slightly discoloured with rust after a shower of rain overnight.

A sample for analysis was obtained from two $\frac{1}{4}$-inch drill holes, 4 feet apart, going to a depth of 2 inches, the surface $\frac{1}{8}$-inch being rejected.

Chemical Examination (By F. Oates).

The sample for analysis consisted of bright steel-like filings and turnings. The material is almost completely soluble in concentrated hydrochloric acid, there being only a minute residue of colourless silica and silicates. In concentrated nitric acid, after the initial effervescence, the iron assumes the usual passive condition. In dilute nitric acid, solution is nearly complete; and the residue contains a few brownish stony grains, in addition to the silica and silicates left by hydrochloric acid. These residues are evidently mainly due to the contamination of the turnings by foreign sandy material. The results of the analysis are:

Fe.	Ni.	Co.	Cu.	Mn.	S.	P.	C.	Insol.	Total.
90·45	8·69	0·66	trace	nil	0·01	0·11	n.d.	0·03	99·95

The fragments of scale, referred to by Dr. Grantham as occurring in the rubble surrounding the meteorite, gave a strong reaction for nickel, and were therefore no doubt derived from the main mass.

Notes on the Structure (By L. J. Spencer).

The piece sawn from the main mass was sent to the British Museum by Dr. E. O. Teale, Director of the Geological Survey of Tanganyika Territory, for polishing and etching and for further examination. It weighed 430 grams, and the cut surface measures 8×5 cm. (about 5 square inches). After smoothing and polishing the cut surface, the weight was reduced to 391·57 grams.

The natural weathered surface of this end-piece shows very distinctly the octahedral structure of the iron. It is cavernous with octahedral surfaces on which there are lamellae in three directions. Cracks parallel to the octahedral faces also penetrate the mass.

The weathered surface showed signs of recent rusting with minute yellow beads (from the sweating out of lawrencite), which gave a strong reaction for chlorine.

Etching with dilute bromine water for fifteen minutes produced little effect, and no prominent Neumann lines were noticed. In very dilute nitric acid beautiful Widmanstätten figures were developed in

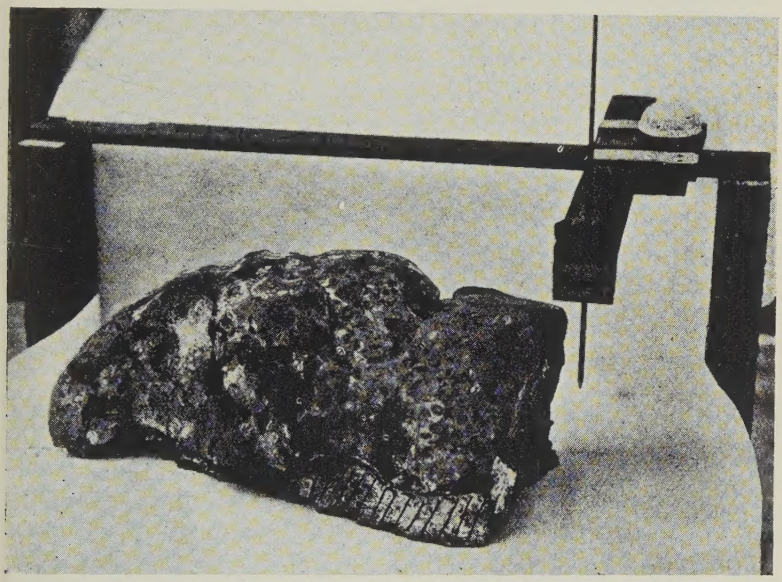


FIG. 3. Model of the Mbosi meteorite, showing the three-dimensional gauge by which it was constructed on one-tenth the scale of the original mass. (Model and photographs of figs. 1–3 by D. R. Grantham.)

one minute, and the etching was stopped after two minutes. The approximately rectangular arrangement of the kamacite bands (plate XIX, fig. 4) shows that the section is approximately parallel to a cube face, and this orientation agrees with the octahedral directions on the weathered surface. The kamacite bands average $\frac{3}{4}$-mm. in width, so that the iron may be classed as a medium octahedrite. Areas of plessite are prominent, but the very narrow bands of taenite are scarcely visible to the unaided eye. One minute speck of troilite was seen on the polished surface, but no schreibersite was detected. A few small angular areas between the kamacite bands show a granular texture with bronze-yellow colour, and perhaps

consist of cohenite. One of these areas is seen as a dark elongated triangle near the centre of fig. 5, and much enlarged in fig. 7. They were prominent on the polished surface before etching. A prominent sheen is shown in certain positions by the different bands of kamacite when the specimen is turned about in reflected light. The orientation of the kamacite bands is uniform over the whole section, indicating that the piece consists of a single individual crystal.

The specific gravity has been determined by Mr. M. H. Hey in the Mineral Department of the British Museum by weighing the whole piece (391·57 grams) in benzene; the value 7·39 so obtained is no doubt too low owing to the presence of cavities and crevices in the specimen. A determination in a pyknometer with carbon tetrachloride made on the filings obtained when smoothing the surface gave values ranging from 7·64 to 7·84. Mr. Hey's analysis of these filings, made for the purpose of trying out a new method of separating the iron by distillation in chlorine, gave:

Fe.	Ni.	Co.	Cu.	S.	P.	C.	Total.
90·65	8·53	0·62	trace	n.d.	n.d.	n.d.	99·80

Determinations of the nickel by the dimethylglyoxime method without separating the iron gave Ni 8·48 and 8·33 per cent.

At the suggestion of Colonel N. T. Belaiew, permission was kindly given by Professor Sir Harold Carpenter for some further work to be done on this interesting meteoric iron in the Metallurgical Laboratory of the Royal School of Mines, South Kensington, London. A determination of the carbon content made on 5 grams of the filings gave C 0·073 per cent. The series of beautiful photographs and photomicrographs reproduced on plates XIX and XX is the work of Dr. J. M. Robertson of that Department. Figs. 4 and 5 were taken of the section as first etched for museum display. This etching was, however, too deep for photomicrographs (figs. 6–11), and the surface was repolished and etched with a 5 per cent. solution of nitric acid in alcohol for about 5 minutes. Fig. 8 shows very clearly that 'plessite' is merely an intergrowth of kamacite and taenite on a smaller scale. The taenite band bordering the kamacite on the right of the picture is seen to branch off into the plessite area. Figs. 10 and 11 (magnification 740) clearly demonstrate that the material of some of the bands called taenite is not a simple substance. This set of photomicrographs indicates that meteoric irons should be more intensively studied by metallographic methods.

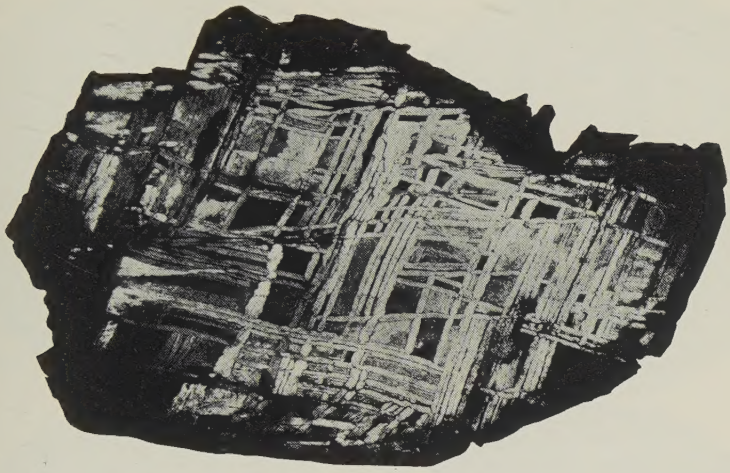


Fig. 4

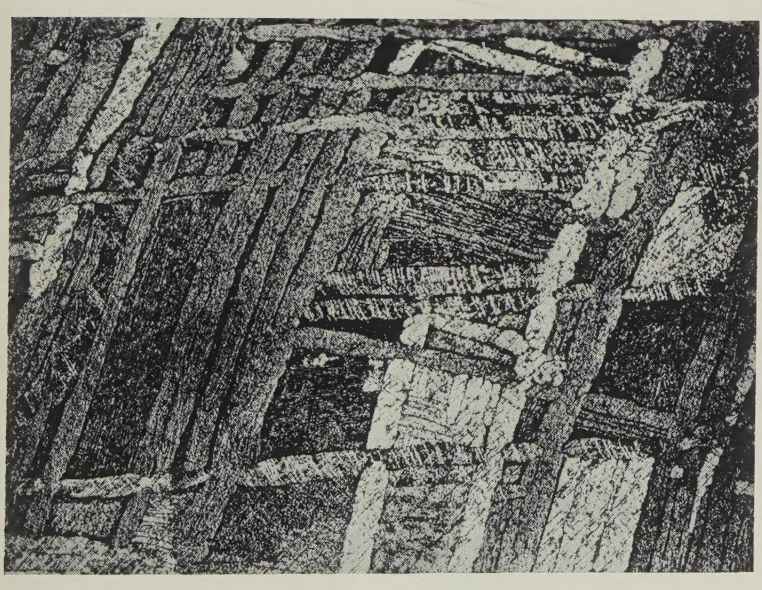
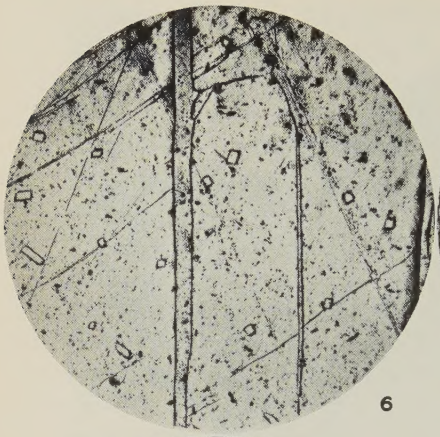
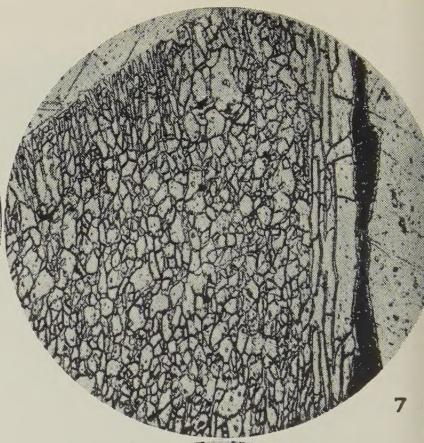
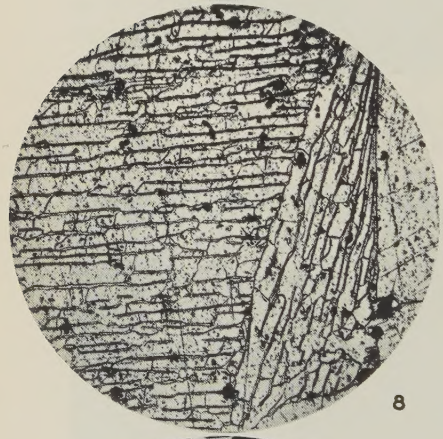


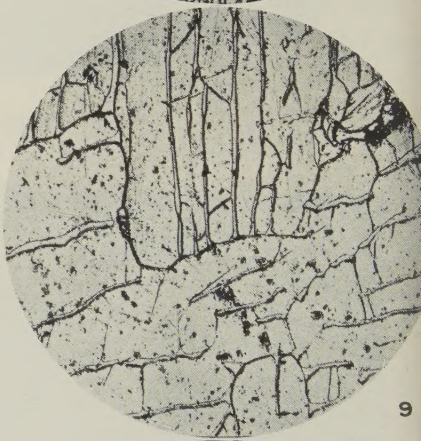
Fig. 5

D. R. Grantham and F. Oates: The Mbosi Meteoric Iron.

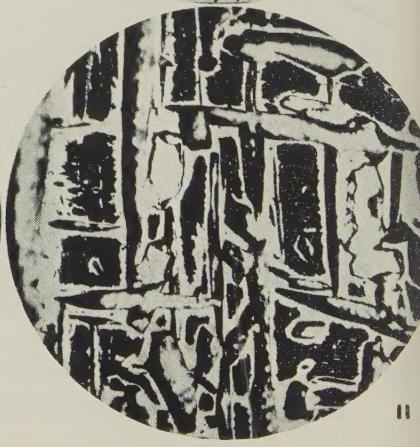

6


7


8


9

10


11

D. R. Grantham and F. Oates: The Mbosi Meteoric Iron.

The Mbosi meteorite thus has characters in common with the many known meteoric irons of the medium octahedrite class, e.g. the Toluca (Mexico) and Cape York (Greenland) irons, agreeing generally with these both in structure and chemical composition. Mr. Oates's analysis gives a Fe/Ni ratio of 10·4, and Ni/Co = 13·2.

Newspaper accounts (e.g. 'The Times', London, of February 17, 1931) gave the weight of this meteorite as 70 (or 84) tons. But it may be mentioned that the 60-ton Hoba[1] meteorite, near Grootfontein in South-West Africa, still holds the record for size of an authenticated meteorite. I am still collecting particulars about the Hoba meteorite and hope soon to give a detailed account.

[1] L. J. Spencer, Min. Mag., 1930, vol. 22, pp. 272–273; Nat. Hist. Mag. (British Museum), 1930, vol. 2, p. 245. Min. Abstr., vol. 4, pp. 261, 422.

Explanation of plates XIX and XX.

Photographs and photomicrographs of the polished and etched section of the Mbosi meteorite, Tanganyika Territory. (Figs. 4–11 by Dr. J. M. Robertson.)

Fig. 4. The whole section (8 × 5 cm.) showing Widmanstätten figures with bands of kamacite and areas of plessite; a reflected sheen is shown by several of the bands of kamacite. The very narrow bands of taenite are not seen. Slightly enlarged, × 1·12.

Fig. 5. Central portion of fig. 4. Neumann lines are shown in some of the kamacite bands. Taenite still only slightly in evidence. × 4.

Fig. 6. Taenite band in the centre and two narrower bands to the right. A few Neumann lines in the kamacite end abruptly at the taenite. The small squares and rhombs are no doubt sections of prisms of rhabdite (= schreibersite). × 90.

Fig. 7. Bronze-coloured granular area (dark elongated triangle near centre in fig. 5, perhaps cohenite), bordered on the right by plessite, then a dark band of taenite, and lastly kamacite. × 40.

Fig. 8. Plessite area of two orientations. The taenite band bordering the kamacite on the right branches off into the plessite area. × 40.

Fig. 9. Plessite area (same as fig. 8), showing bands of kamacite (with a few Neumann lines) bordered by taenite. × 90.

Fig. 10. Taenite band (the dark band in fig. 7). × 740.

Fig. 11. Another taenite band. × 740.

The Dhoon (Isle of Man) granite: a study in contamination.

By S. R. Nockolds, M.Sc.
Sedgwick Museum, Cambridge.

[Read March 17, 1931; communicated by the General Secretary.]

THE Dhoon granite is contained in sheets 8 SW. and 8 SE. of the 6-inch Ordnance Survey Maps of the Isle of Man. It is a boss-like intrusion of irregular outcrop (fig. 1), enclosing an area about one and one-third miles long in an east-west direction, and half a mile wide in a north-south direction. It has been intruded into rocks which form part of that division of the Manx slates known as the Lonan Flags, and has metamorphosed these to a certain extent.

Berger,[1] Henslow,[2] and Cumming[3] all give brief descriptions of the granite, but it was not until Lamplugh[4] visited the island on behalf of the Geological Survey that any further progress was made. He mapped and described the outcrop of the granite accurately (loc. cit. pp. 142–144) and W. W. Watts described some micro-sections of the granite and its associated rocks (loc. cit., pp. 312–314). The granite was termed by him a porphyritic microgranite. Actually, however, the granite is a product of contamination, and in the following pages the evidence for this statement is set forth in detail.

Petrology of the Granite.

Examination of the intrusion has shown that two well-defined varieties of the granite (Types A and B) are present. Type B is restricted to a small area near Kionehenin, the boundaries of which cannot be located with any precision. It also occurs as inclusions of varying size in Type A.

[1] J. F. Berger, Mineralogical account of the Isle of Man. Trans. Geol. Soc. London, 1814, ser. 1, vol. 2, pp. 29–65.

[2] J. S. Henslow, Supplementary observations to Dr. Berger's Account of the Isle of Man. Ibid., 1821, ser. 1, vol. 5, pt. 2, pp. 483–505.

[3] J. G. Cumming, The Isle of Man. London, 1848.

[4] G. W. Lamplugh, The geology of the Isle of Man. Mem. Geol. Survey United Kingdom, 1903.

Type A Granite.—In hand-specimens this is a rather fine-textured medium grey rock, with small phenocrysts of white felspar and pale-blue opalescent quartz. A noticeable feature is the irregular distribution of the biotite flakes and their tendency to occur in small clots, giving the whole rock a patchy appearance. These are set in a finer groundmass of the same constituents. Inclusions of a dark

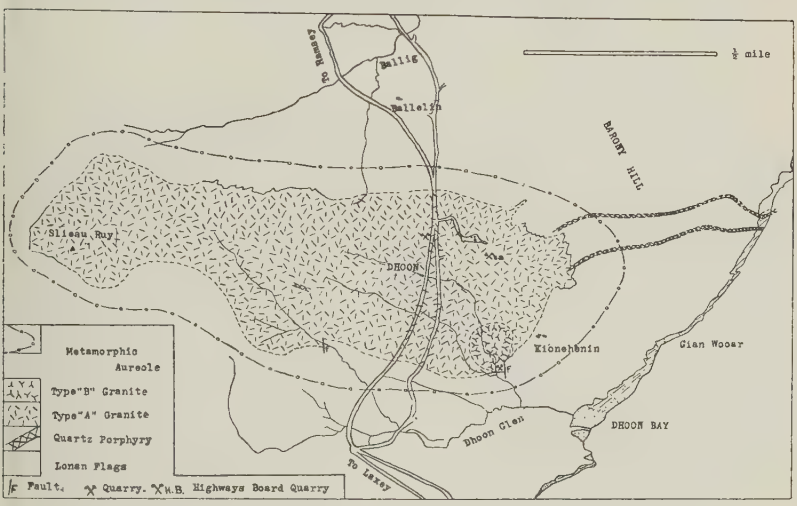


FIG. 1. Sketch-map of the granite mass, Dhoon, Isle of Man. (Scale, 2 inches to 1 mile.)

rock are of very common occurrence. They are usually of small size and, indeed, are often but little larger than the biotite clots.

The felspar phenocrysts vary considerably in size; all have fairly good outlines, though sometimes rather marred by the encroachment of the groundmass. The largest measured was $6\frac{1}{4} \times 2$ mm., but sizes grouped around 2×1 mm. are the most frequent. Anything below this has been taken as belonging to the groundmass. This is a purely arbitrary arrangement because the felspars show seriate texture. These phenocrysts are all of plagioclase and have the composition $Ab_{95}\ An_5$. Even in the freshest specimens the felspars show a great deal of alteration with the production of zoisite and white mica, and sometimes a little chlorite and quartz. The alteration is apparently of pre-solidification date, because nearly every phenocryst is surrounded by a narrow rim of fresh felspar in optical continuity with and of the same composition as the felspar of the interior. Whatever

the explanation of this alteration may be, there is no doubt that the plagioclase phenocrysts must originally have been more basic than they are now. This is borne out by the norm as calculated from the analysis. The process is thus essentially one of albitization. Lamellar twinning on the albite-law is a constant phenomenon, twinning on Carlsbad- and pericline-laws being less common. Zoning occurs but rarely, and always in specimens taken near the contact, where it has been favoured by rapid cooling. The zones, as far as could be determined, do not vary greatly in composition.

The quartz phenocrysts are present as rounded grains with sizes comparable to those of the felspar, but they do not show the same seriate arrangement. They form between 25 % and 40 % of the total phenocryst content in various specimens. All are more or less strained, but the intensity varies a good deal and a much-strained grain may lie next to an almost unstrained one. In places they are much cracked. Liquid and gas inclusions are of common occurrence, and sometimes mark out the rift and grain directions. Small rutile needles are frequent as inclusions. The phenocrysts of felspar and quartz together may make up anything from about 23 % to 30 % of the whole rock.

The biotite clots may occur close together or they may be more or less scattered. The biotite occurs as ragged flakes which show strong pleochroism from a pale straw-colour to a foxy-brown, sometimes inclined to be 'muddy'. Pleochroic haloes round small zircons are constantly present though not particularly abundant. There is also, quite frequently, a decided darkening of colour round inclusions of zoisite, suggesting that this too may be slightly radioactive. In some flakes the biotite may show a kind of schiller structure, due to bundles of minute needles of brown magnesian tourmaline lying along the cleavage planes. Sometimes this tourmaline occurs intergrown with the biotite as definite crystals and appears to be replacing it. Rutile is present in some instances, forming sagenite webs in varying stages of perfection.

The biotite clots may contain many flakes or, in rare cases, only one, but all show the same general features. In every case the biotite is associated with one or more of the following minerals: prisms of zoisite; ilmenite, generally with a border of granular sphene; more rarely sphene alone; occasionally grains of epidote and clinozoisite; and grains of garnet. These may be included in the biotite or lie at the margins of the flakes. A feature of the clots

is the abundance of apatite needles in their immediate vicinity. There is good reason to believe, both from the constitution of the clots and from the evidence afforded by the inclusions which occur in the granite, that these clots are not normal but are derived from inclusions of another rock which have been more or less completely digested by the magma.

The groundmass of the rock is composed of quartz, felspar, and biotite. The texture is governed by the fact that the felspars have

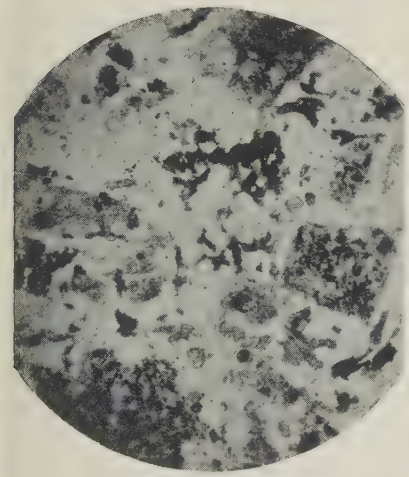


Fig. 2.

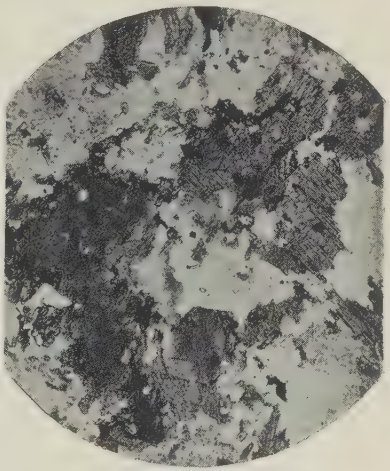


Fig. 3.

Fig. 2. Granite, Type A, showing the alteration of the felspar phenocrysts, and free from biotite clots. The specimen analysed. Ordinary light, ×24.

Fig. 3. Biotite clot. Another portion of the same slide as fig. 2. Biotite with ilmenite, sphene, some zoisite, and apatite needles in the vicinity. Ordinary light, ×40.

a strong tendency towards idiomorphic outline, whilst the quartz is granular. It is best described as micrographitic. The quartz grains are the most abundant constituent of the groundmass, and they show no signs of strain. They occur either partially or wholly included in the felspars or else fill up the interstices between them; or in places form a rough micrographic intergrowth. The next most abundant constituent is the plagioclase felspar (albite), the larger crystals of which are somewhat altered, but most of the smaller ones are quite fresh. Orthoclase, perthite, and microcline also occur, but only in small quantity. This was proved by etching

a section with hydrofluoric acid and then testing for potash with sodium cobaltinitrite. Of these three potash-felspars, the first is the most abundant, the last is rare. The biotite flakes of the groundmass have the same colour and pleochroism as the larger ones that occur in the clots. How far they are original is unknown. It is, however, interesting to find that in a section particularly rich in clots the groundmass biotite was also more abundant than usual.

Accessory minerals include apatite, zircon, and rutile, already mentioned. There is also a fair amount of pyrite, a little magnetite, and in certain parts a little molybdenite. Calcite may also occur in the groundmass of the fresh granite, and in this sense is a primary constituent.

Type B Granite.—This is a black and white speckled rock, the black of the mica contrasting with the white of the felspar. The biotite aggregates are, on the whole, noticeably larger. Amongst the white portions of the rock grains of pale-blue opalescent quartz may be seen. The texture is granitic. Inclusions of a dark rock, similar to that found in Type A, are present in abundance, but are found to be of larger size and often have sharper outlines, as if this type has not been able to digest them as completely as Type A.

The minerals which occur are of the same nature as those already described under Type A. In this type, however, there is little or no groundmass present and the texture becomes normally granitic. The biotite clots are larger in this type, which gives it the appearance of containing more biotite than Type A. This is the case to a certain extent. It is interesting to note that Type A granite has good 'cleavage' whilst Type B has none.

Relationship of Type A to Type B.—The relationship of Type A to Type B is only shown in one place. This is the Highways Board Quarry where Type B forms a lenticular mass enclosed in Type A at the SE. corner of the quarry. At the time of visiting, the junctions were covered by quarry debris, and the information given below is due to Mr. Corteen, the quarry foreman.

The mass is completely surrounded by Type A, the top being about twelve feet below the quarry top. It passes gradually into Type A, there being no sharp junctions.

Three explanations are possible : (*a*) the whole granite mass represents a single intrusion in which certain portions (perhaps owing to richness in volatile constituents) were able to attain a normal

granitic texture; (*b*) Type B represents portions which had crystallized at a greater depth, i.e. during the phenocryst stage of Type A, and have been carried up by Type A to their present position; (*c*) Type B is the remnant of a slightly earlier intrusion, which was overwhelmed, whilst still hot, by Type A. Taking all the facts into consideration, explanation (*c*) would seem the most probable.

Variations of the granite as a whole.—The granite (and this virtually means Type A, as Type B only forms a small proportion of the

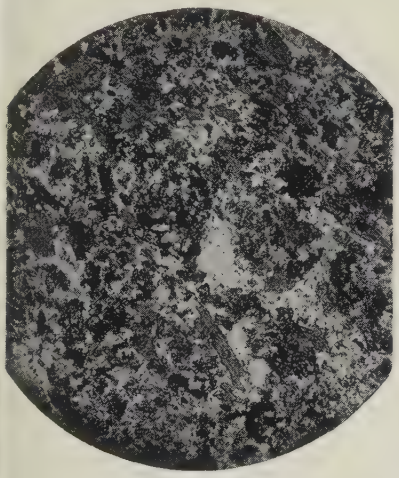


Fig. 4.

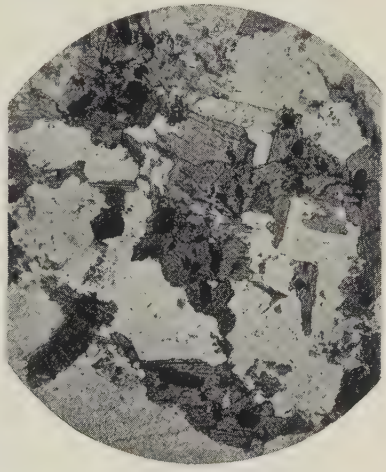


Fig. 5.

Fig. 4. Centre of typical inclusion. Biotite, zoisite, ilmenite, sphene, paragonite, and albite are all present. Ordinary light, ×40.

Fig. 5. Biotite clot forming at the margin of an inclusion. Compare fig. 3. Ordinary light, ×40.

whole) varies in its biotite content from about 10–15 %. Locally, near inclusions or in patches where biotite clots are abundant, it may reach a much higher figure. The specific gravity varies from 2·68 to 2·76 in various specimens. It is found that there is a general tendency for the groundmass to become more siliceous in the higher portions of the intrusion. Further, at the actual contact with the Lonan Flags the biotite of the granite is converted to chlorite, often accompanied by secondary sphene, and secondary white mica is developed at the expense of the felspar.

Chemical composition and classification of the granite.—A sample of the most normal-looking portion of Type A granite that could be

found was chosen for analysis, and the result is given below, together with other analyses for comparison :

	I.	A.	B.	C.
SiO_2	71·20	72·33	71·70	72·55
Al_2O_3... ...	14·73	14·56	16·81	14·13
Fe_2O_3... ...	0·41	0·15		0·65
FeO	2·39	2·22	—	1·79
MgO	0·89	0·91	0·47	nil
CaO	3·06	2·55	2·42	3·53
Na_2O... ...	3·50	3·40	9·00	4·47
K_2O	2·12	2·82		2·71
H_2O+ ...	0·80	0·30	—	0·37
H_2O- ...	0·20	—	—	—
CO_2	nil	nil	—	—
TiO_2	0·18	—	—	—
P_2O_5	0·12	—	—	trace
MnO	trace	—	—	—
S	0·30	—	—	—
Ni,Co,Zn ...	nil	—	—	—
	99·90	99·24	100·40	100·20

I. Dhoon Granite (Type A), Highways Board Quarry, Dhoon, Isle of Man. Analysts, W. H. and F. Herdsman.

A. Dacite, Kemp Mountain, North Carolina. Analyst, J. E. Pogue, 1909.

B. Aplodiorite, Inner Granite, Ben Nevis, Scotland. Analyst, B. Lightfoot, 1916.

C. Adamellite-porphyry, Okurra, Fukai Island, Japan. Analyst, E. Yokoyama, 1913.

The norm of analysis I, calculated in the usual way, is as follows :

Quartz	34·23	Corundum	1·43
Orthoclase	12·23	Pyrite	1·08
Albite	29·34	Magnetite	0·70
Anorthite	14·46	Ilmenite	0·46
Hypersthene $FeSiO_3$ ...	3·04	Apatite	0·34
Hypersthene $MgSiO_3$ ...	2·20	Water	0·80

The calculated mode is :

Quartz	36·42	Pyrite	1·08
Orthoclase	6·67	Magnetite	0·70
Plagioclase ($Ab_{67}An_{33}$) ...	43·80	Ilmenite	0·46
Biotite	10·64	Apatite	0·34

It will be seen that even allowing for the lime contained in the zoisite and sphene of the biotite clots, the plagioclase of the norm and the calculated mode will be at least as basic as $Ab_{75}An_{25}$. This gives some idea of the original composition of the plagioclase before

it was albitized. The point is dealt with further under the heading of the contamination process.

The analysis shows that the rock falls into the granodiorite group except for the fact that ferric oxide is rather low, whilst silica is high. Although chemically and, to some extent, mineralogically a granodiorite or granodiorite-porphyry, yet the association of zoisite, ilmenite, sphene, &c., with the biotite shows that the rock is not of normal type. In the following pages, evidence is brought forward to show that this rock is a product of contamination.

The Inclusions of the Granite and the Contamination Process.

Inclusions are rather abundantly distributed throughout the granite. They can be divided into three classes:

I. Inclusions found only near the contact and derived from the surrounding Lonan Flags. These are not particularly abundant. They do not show any features of particular interest, being composed essentially of biotite and muscovite in a groundmass of quartz with a certain amount of felspar (probably albite). The biotite may be partly or wholly chloritized and may give the rock a pronounced foliation. Magnetite is associated with it. The inclusions are fine-textured, and there has been but little recrystallization. These inclusions have sharp boundaries against the granite and show no signs of assimilation.

II. Inclusions of sedimentary origin from some greater depth. One inclusion was found, about the size of a large biotite clot, which was composed of pink pleochroic andalusite and biotite. It had no definite boundaries with the granite, and obviously represents a small piece of slate which has been completely recrystallized.

III. Inclusions of igneous origin, derived from greater depths and responsible for the contamination of the granite. It has been mentioned before that inclusions of a dark rock are distributed throughout both types of granite. These are the ones that come under the present heading. They are better defined and appear to be more abundant in Type B granite than in Type A, but this would seem to be chiefly due to the fact that Type A was able to disintegrate and incorporate them more effectually than Type B. These inclusions are all of small size, ranging from several inches down to the size of the biotite clots already described in connexion with the granite.

Viewed macroscopically, the inclusions of the last class are black or dark brown in colour, and sometimes show sharp boundaries with

the enclosing granite; in other cases this boundary is not so well defined.

Under the microscope, it is evident that they have been completely recrystallized. They now consist of an aggregate of biotite plates showing pleochroic haloes, zoisite prisms of small size, white mica as tiny flakes, and granular albite. Sphene and ilmenite (generally with a border of granular sphene) are nearly always present in some quantity, a pale pink isotropic garnet is sometimes present, and rarely there is a little epidote and clinozoisite. The relation of the white mica to the albite is interesting. Some inclusions are in a more advanced stage of dissolution and alteration than others. In these the albite seems to replace gradually the white mica, a phenomenon which can also be noticed towards the margins of the inclusions. This antipathetic relation shows that, in all probability, the white mica is paragonite.

Other inclusions, whilst still preserving their original outline to a limited extent, show a more advanced stage of dissolution. In these, the white mica has been almost entirely replaced by albite, and quartz begins to occur throughout, but more especially in certain coarser areas. These inclusions have often been partially disrupted by the granite and the smaller pieces have floated away for a short distance. In these detached portions the biotite and zoisite are noticeably larger in size.

This assemblage, consisting essentially of biotite, zoisite, paragonite and (or) albite, is a very striking one and appears to be unique in that it has not been described before. It is a hydrothermal assemblage, and its occurrence here must be due to the fact that the magma which enveloped these inclusions was rich (perhaps exceptionally rich) in volatile constituents, especially water. This is borne out by the fact that the metamorphism produced in the surrounding flags is of a hydrothermal nature and has led to an extensive development of muscovite and chlorite. Further, there are quartz and quartz-tourmaline veins trending roughly north-south which are connected with the granite.

The most interesting feature of the more altered inclusions occurs, however, at their margins. Streaming out from the inclusion into the surrounding granite, masses of material can be seen which are, to all intents and purposes, biotite clots such as those described when dealing with the granite. The biotite flakes are larger than those present in the body of the inclusion and the zoisite prisms

have also grown bigger. The ilmenite has its border of granular sphene and separate grains of sphene may be present. Their resemblance to the biotite clots which occur throughout the whole granite is very pronounced. These masses represent the last remnants of the portions of the inclusions which have been completely replaced by the granite. The albite and quartz probably actually went into solution in the magma (being low in the reaction series); while the biotite and its accompanying minerals have been left, as the magma could not dissolve them but only convert them into minerals with which it would be as far as possible in equilibrium.

Thus we appear to have all stages from the recrystallized inclusion down to the biotite clots preserved to us. Is it too much to suppose that the clots which are found in the granite, remote from any definite inclusion, have in reality been derived from the complete dissolution and disintegration of other inclusions? There seems little doubt that their origin must be attributed to some such cause.

What, then, was the nature of the original material which gave rise to these inclusions and clots? In the first place, it was rich in ferromagnesian material and comparatively rich in ilmenite. In the second place, it was rich in lime, but poor in quartz. The surrounding Lonan Flags obviously will not fit the case and it seems doubtful if any sediment would. On turning to the igneous rocks we have very suggestive support from one of the greenstone dikes which occur so frequently throughout the Manx Slates.

This dike is cut by the quartz-porphyry dikes (see map, fig. 1) which run from the granite to the coast. These dikes are later than the granite but obviously connected with it. They are quite normal quartz-porphyries with phenocrysts of quartz, felspar, and, more rarely, micropegmatite set in a fine-grained groundmass. The quartz may or may not have the pale-blue colour characteristic of that in the granite. The felspar phenocrysts are of albite with subordinate orthoclase, microperthite, and microcline. The groundmass in which these are set is composed of quartz, albite, potash-felspar, and small flakes of muscovite. This groundmass has on the whole a granular texture, but sometimes its little orthoclase crystals are fringed with a delicate growth of micropegmatite. Biotite, small ill-developed garnets, and sphene may sometimes be present and are usually associated together, but they are not essential constituents.

Near the contact with this quartz-porphyry, the greenstone dike shows that it has undergone thermal metamorphism in addition to

its earlier regional metamorphism. At about three feet from the contact the greenstone consists of large and smaller crystals of an actinolitic hornblende set in a matrix which is composed of small flakes of white mica, zoisite, and a little albite. Ilmenite and leucoxene are present, and in places biotite is just beginning to develop from the amphibole. A specimen taken half an inch from the contact shows the most striking changes. Here the actinolite has almost completely disappeared, its place being taken by biotite. The rock now consists of biotite, zoisite, granular sphene, and ilmenite with a certain amount of albite and quartz. This assemblage is essentially the same as that found in the inclusions, and it seems fairly safe to say that they must have arisen from a rock similar in composition to the greenstone dike.

It now remains to discover how the inclusions attained their present assemblage, and what effect this may have had on the granite magma. It is immediately obvious that potash must have been introduced from the magma, and from examination of the amount of zoisite present in the inclusions one would say that lime has been lost to the magma. There may also have been other changes. With a view to determining this, analyses of a greenstone identical with the one described above, of an inclusion, and of one of the quartz-porphyry dikes have been made. One of the granite has already been given and is reproduced here for ease of reference. These are as follows :

	I.	II.	III.	IV.
SiO_2	45·70	50·70	71·20	75·40
Al_2O_3... ...	16·92	23·40	14·73	13·05
Fe_2O_3... ...	0·90	1·77	0·41	0·51
FeO	8·44	5·02	2·39	0·70
MgO	9·41	2·35	0·89	0·49
CaO	10·42	3·80	3·06	0·72
Na_2O... ...	1·81	4·45	3·50	3·92
K_2O	1·02	4·38	2·12	3·87
H_2O+ ...	3·00	2·40	0·80	1·00
H_2O- ...	0·30	0·10	0·20	0·20
CO_2	nil	nil	nil	nil
TiO_2	1·80	1·14	0·18	0·18
P_2O_5	trace	0·08	0·12	0·07
MnO	0·36	0·18	trace	nil
S	trace	0·29	0·30	trace
Ni,Co,Zn ...	nil	nil	nil	nil
Total	100·08	100·06	99·90	100·11

I. Greenstone dike.
II. Inclusion.
III. Granite.
IV. Quartz-porphyry dike.

Analysts, W. H. and F. Herdsman.

It must be remembered that the granite chosen for analysis was one of the least contaminated specimens that could be found. It would doubtless be easy to find others with higher content of FeO and MgO. The quartz-porphyry dike shows no signs of any contamination, and is probably somewhere about the composition of the original granite magma before contamination (excluding, of course, volatiles, &c.).

Dealing first with the greenstone dike and inclusions derived from it, we find that the inclusion loses ferrous oxide, magnesia, and lime, but gains a considerable amount of potash, soda, and alumina. On the other hand, the granite as compared with the uncontaminated quartz-porphyry dike loses potash and soda, but gains ferrous oxide, magnesia, and especially lime. Thus we have here that reciprocal reaction which is the very basis of contamination.

It is to be noted that the inclusions are in no sense intermediate in composition between the greenstone and the quartz-porphyry, or between the greenstone and the contaminated granite. No mixtures of these could produce the inclusions; in other words, the reactions that went on were selective in character and emphasized certain constituents. Further, the contaminated granite gains ferrous oxide, magnesia, and lime in two ways. It gains these oxides when attempting to incorporate the inclusions because the biotite clots with their zoisite, &c., are left as relics, and it also gains them by the reciprocal reaction mentioned above.

The Loch Ailsh intrusion, although a syenite, shows considerable similarity in its reactions to the Dhoon granite.[1] On p. 99 the authors state that 'The sediment absorbs potash to form biotite with the magnesia of the dolomite, and the igneous rock absorbs lime. . . '. Again, on p. 101 it is stated that 'Pyroxene is never present, though masses of zoisite and biotite may have a prismatic outline as if they were replacing pyroxene. . . '. At Arnage in Aberdeenshire[2] the norite gains alumina and potash, but loses lime and magnesia to the xenoliths. Shale xenoliths in the norite of the Bushveld Complex[3] lose alumina and gain magnesia and lime. In Mull[4] the xenoliths of the tholeiite dikes gain lime, ferrous iron, and magnesia. Other cases are known where similar reactions occur.

[1] Mem. Geol. Survey Scotland, Expl. Sheet 102, 1926.
[2] H. H. Read, Quart. Journ. Geol. Soc. London, 1923, vol. 79, pp. 479–484.
[3] A. L. Hall and A. L. du Toit, Trans. Geol. Soc. S. Africa, 1924, vol. 26 (for 1923), p. 85.
[4] H. H. Thomas, Quart. Journ. Geol. Soc. London, 1922, vol. 78, p. 253.

Summing up, we may say that in the present state of knowledge it is found that lime, ferrous oxide, and magnesia are associated on the one hand, and potash, soda, and alumina on the other. Further, it is apparent that there is some sort of reciprocal relation between these two sets of oxides. The exact nature of this relationship is a subject for future research.

The transference of material to and from the inclusions can be explained in several ways, and until we have more knowledge of other examples, the matter must be of a more or less speculative nature. It might be due to some sort of absorption by the inclusion. Again, it may be due to the existence of a reciprocal salt pair or series of such pairs, but it would be a matter of some difficulty to determine this. Finally, it may quite well be due to the preferential leaching out of certain constituents from the inclusions by the volatiles present in the magma, these being replaced by material that they carry with them. It must be remembered that the magma is a melt of curious physical constitution. It contains viscous silicates and highly mobile volatiles. Even if these volatiles form compounds with the silicates, those compounds will tend to move with the volatiles rather than with the other silicates. Soluble silicates, such as those of potash and soda, will almost certainly form part of the volatile portion of the magma. Thus this portion will contain plenty of material with which to effect change in the inclusions.

In the present instance there is evidence of a preferential absorption of volatile constituents by the inclusions. All the minerals of the inclusion either have water of constitution or require water for their formation. Again, the abundance of apatite in the immediate vicinity of the biotite clots and in the inclusions shows that the volatiles were concentrated in the neighbourhood. The abundance of apatite in the immediate vicinity of clots and inclusions has been noted by various writers, and Wandke[1] has drawn special attention to its significance.

Preferential absorption is perhaps enhanced by the fact that the volatiles and the otherwise viscous melt must have a continuous tendency to 'unmix'. This absorption is a physical process and is followed, probably immediately, by interchange of material with reciprocal reaction—that is to say, a chemical process superimposed on a previous physical one. Whether this will hold for all inclu-

[1] A. Wandke, Amer. Journ. Sci., 1922, ser. 5, vol. 4, p. 156.

sions in all magmas is a subject for future work. No great degree of superheat is required for the contamination process. Bowen [1] has shown that superheat is only needed to bring the inclusions up to the temperature of the magma. After that reactive precipitation plays the dominant rôle.

Under the conditions prevailing in the magma, biotite was the only ferromagnesian mineral which could form. The magma could and did react with inclusions in such a way as to produce biotite from the original ferromagnesian material. In like manner zoisite (owing to its large solid specific volume) would be more stable than its analogue anorthite. So the magma reacted with the inclusion to produce zoisite from the anorthite molecule. All this probably took place while the magma was still largely uncrystallized. As crystallization proceeded and the magma became more viscous, it became prominent as a disrupting agent. The inclusions were broken up and small pieces floated off or were strewn about. That there was movement in the magma is shown by the fact that the biotite flakes of the groundmass, and even a clot itself, can sometimes be seen winding round a phenocryst.

Another remarkable feature of the granite can be attributed to its contamination. We have seen that the inclusions must have given lime to the magma in some quantity. This resulted in the early crystallization of a plagioclase felspar fairly rich in lime. Allowing for a certain amount of lime in the zoisite, sphene, &c., of the biotite clots, its composition as deduced from the norm of the granite already given was somewhere about $Ab_{75}An_{25}$. It may be noted here that Grantham [2] in dealing with the Shap granite, says 'A high content of biotite, sphene, and calcic plagioclase would be expected as the result of assimilation of a basic rock'.

In the present instance, however, this was not the whole story. As crystallization proceeded, the concentration of the soda molecules in the remaining liquid gradually became greater until the felspars, apparently not reacting quickly enough to keep pace with this enrichment, were completely out of equilibrium. The result was that the soda more or less completely replaced the lime of the felspars, which was thrown out in the form of zoisite. Bowen (loc. cit., p. 267) states that 'minerals may be desilicated in the presence of alkalic molecules'. This, no doubt, helped in the formation of

[1] N. L. Bowen, The evolution of the igneous rocks. Princeton, 1928, Chapter X.
[2] D. R. Grantham, Proc. Geol. Assoc. London, 1928, vol. 39, p. 328.

zoisite from the anorthite molecule. Water also left its mark on the reaction in the formation of paragonite from some of the soda molecule. Finally, when equilibrium was properly adjusted, a narrow rim of fresh soda-felspar was deposited round the crystals. Thus the alteration of the larger felspars of the granite, as previously described, was indirectly dependent on contamination. A rather similar alteration of felspars has been described by Goodspeed.[1] It is of special interest to find that he regarded the alteration of his early plagioclase-felspars as being connected with the absorption of schist by the magma with which he was dealing.

We have, then, been led to the conclusion that the Dhoon granite is a contaminated rock resulting from an alkali-granite magma which has absorbed basic igneous material. The fact that there is no trace of any appreciable amount of other material forming the inclusions, renders it probable that the magma was intruded into an older basic intrusion occupying much the same position as the present granite.

As the greenstones intruded into the Manx slates had been sheared before the intrusion of the granite, it seems reasonable to suppose that this older basic intrusion would also be in a sheared condition. This would help in the conversion of the basic rock into biotite, zoisite, &c., as there is a striking similarity between the minerals formed under stress conditions and those formed in a 'wet' magma.

The contamination has produced a rock which is chemically a granodiorite, falling into a normal rang and subrang, showing once again the fallacy of classifying rocks according to their chemical composition alone. Mineralogically, zoisite and ilmenite with a granular sphene border are minerals not found normally in rocks of granitic type, and these give the clue which leads to the determination of the true nature of the rock.

Summary and Conclusions.

1. The Dhoon granite forms a boss-like mass extending for about $1\frac{1}{3}$ miles in an east-west direction and for about half a mile in a north-south direction. It is intruded into the Lonan Flags which form part of the Manx Slate Series.

2. Detailed examination shows that two main types of granite are present, one of which is slightly earlier in date than the other and only forms a very small portion of the present outcrop. The difference between the two types is mainly textural.

[1] G. E. Goodspeed, Journ. Geol. Chicago, 1927, vol. 35, p. 662; 1929, vol. 37, p. 158.

3. The main mass of the granite may be termed a biotite-granodiorite-porphyry, whilst the other type present is a biotite-granodiorite. Both types are abnormal, however, in that the biotite occurs in clots and in association with any or all of the following minerals: zoisite, ilmenite (usually with a border of granular sphene), sphene, and, more rarely, epidote or clinozoisite, and garnet.

4. It is shown that these clots represent the last remnants of a basic igneous rock which has been absorbed by the original granitic magma. Further, this basic rock had almost certainly been regionally metamorphosed before incorporation and probably occupied much the same position as the present granite boss. Inclusions of this rock, now altered to an aggregate of biotite, zoisite, ilmenite with sphene border, sphene, albite, and (or) paragonite, with rarer garnet and clinozoisite, are present in both types of granite, and all stages in the formation of the biotite clots from these inclusions can be studied.

The theoretical aspects of this contamination are discussed, and it is finally concluded that the original magma was of alkali-granite type, poor in ferromagnesian minerals and similar in composition to the quartz-porphyry dikes which are associated with the 'granite'. In addition, all the evidence points to an extensive interchange of oxides between the original magma and the basic inclusions. Further, it is shown that the peculiar albitization of the felspars in the 'granite' of both types is indirectly dependent on the contamination.

Acknowledgements.—The author wishes to express his best thanks to Dr. H. H. Thomas, who originally suggested the examination of the intrusion; to Prof. O. T. Jones and Dr. M. B. Hodge, under whose supervision the work was done; to Mr. G. Barrow for much useful advice and for the gift of thin sections; to Dr. C. E. Tilley for kindly reading the manuscript; to Mr. P. M. C. Kermode of the Manx Museum; and finally to Miss H. Jackson for much help in the preparation of the manuscript.

On pink epsomites and fauserite.

By Max H. Hey, B.A., B.Sc.
Assistant-Keeper in the Mineral Department
of the British Museum of Natural History.

[Read June 3, 1930.]

IN 1865 A. Breithaupt[1] described a new mineral from Herrengrund, Hungary, to which he gave the name of fauserite. It formed very pale pink crystalline aggregates and prismatic crystals, with prism angle near 88° 42′ (over *a*), apparently orthorhombic, and cleavage *b* (010). Two other prisms with angles (over *a*) 54° 39′ and 107° 50′ were observed, and a pyramid *p*, giving *mp* = 52°; these would correspond to forms (210), (340), and (111), and the angles are near those of epsomite. An analysis by Mollnár[2] gave the figures shown under I below—a magnesium and manganese sulphate hexahydrate, with the molecular ratio $MgSO_4/(Mn,Mg)SO_4$ = 31·62 %. There is no evidence that the analysed material (stated to be crystalline) was homogeneous.

Some years later, J. Loczka[3] studied material of similar appearance from Hodrusbánya, Hungary, which (evidently going by the similarity in appearance) he also styled fauserite; but his analysis (II below) showed a very striking difference from Mollnár's. His material was clearly a pink epsomite, the colour being due to traces of cobalt; manganese was present in only small quantity, and there were also traces of zinc and iron.

After referring to these two descriptions, Dana[4] remarks that Loczka's work throws some doubt on the real existence of a fauserite corresponding to Breithaupt's original description and analysis. In the hope of at once obtaining evidence on this point and allocating the specimens to the proper species without question, the author

[1] A. Breithaupt, Berg- und Hüttenmännische Zeitung, 1865, vol. 24, p. 301.

[2] The second analysis quoted by Dana is Mollnár's theoretical figures.

[3] J. Loczka, Math. Természett. Közlem. Budapest, 1891, vol. 24, p. 350; Math. Naturwiss. Ber. aus Ungarn, 1891, vol. 8 (for 1889–1890), p. 108.

[4] J. D. Dana, Syst. Min., 6th edit., 1892, p. 941.

TABLE I.

Analyses of pink epsomites and fauserite.

		I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Percentages.	SO_3	34·49	32·52	32·90	34·15	32·53	32·33	31·54	32·62	32·92
	MnO	19·61	0·25	0·56	0·20	0·38	0·40	4·28	0·32	0·33
	MgO	5·15	15·47	15·98	17·24	16·93	15·24	12·76	14·58	15·59
	CoO	—	0·08	0·31	1·06	0·23	0·11	0·068	nil	0·11
	NiO	—	—	0·13	0·07	trace	trace	trace	nil	0·002
	FeO	—	0·04	0·024	trace	0·006	0·049	0·015	0·051	0·023
	ZnO	—	0·54	0·15	0·17	0·19	0·53	2·82	0·94	0·25
	H_2O	42·66	50·73	50·20	47·44	49·59	51·10	48·41	50·21	49·36
	Insol.	—	—	0·05	0·20	trace	trace	trace	1·02	1·00
Total ...		101·91	99·63	100·30	100·53	99·86	99·75	99·89	99·74	99·58
Molecular parts (total bases = 100).	SO_3	106·70	102·62	99·11	95·26	94·28	102·90	95·30	107·60	103·75
	MnO	68·38	0·89	1·93	0·64	1·26	1·45	14·78	1·21	1·19
	MgO	31·62	96·98	96·04	95·53	97·47	96·34	76·57	95·55	97·58
	CoO	—	0·28	1·00	3·16	0·71	0·37	0·22	nil	0·37
	NiO	—	—	0·53	0·21	trace	trace	trace	nil	0·01
	FeO	—	0·14	0·08	trace	0·02	0·17	0·05	0·19	0·08
	ZnO	—	1·68	0·42	0·46	0·56	1·67	8·38	3·05	0·77
(Total bases = 1).	H_2O	5·86	7·114	6·72	5·88	6·39	7·23	6·50	7·36	6·91
	Sp. gr.	1·888	1·670	1·68	1·68–9	1·73–5	1·68	1·70	1·70	1·68

I. Herrengrund, Hungary (now Španá Dolina, Czechoslovakia). A. Breithaupt, 1865 (loc. cit.).

II. Hodrusbánya, Hungary (now Hodruša, Czechoslovakia). J. Loczka, 1891 (loc. cit.).

III. Neusohl, Hungary (now Baňská Bystrica, Czechoslovakia). B.M. 33179. Extinction straight, 2E ca. 80°.

IV. Neusohl, Hungary (now Baňská Bystrica, Czechoslovakia). B.M. 60538. 2E ca. 80°, negative.

V. Locality unknown. B.M. 61317. 2E medium large, negative.

VI. Herrengrund, Hungary (now Španá Dolina, Czechoslovakia). B.M. 42916. Extinction straight, 2E ca. 83°. $Bx_a \perp$ cleavage.

VII. Schemnitz, Hungary (now Štiavnica, Czechoslovakia). B.M. 44274. Extinction straight, 2E 76–80°, negative, $Bx_a \perp$ cleavage.

VIII. Hodrusbánya, Hungary (now Hodruša, Czechoslovakia). B.M. 1907,878. Extinction straight, 2E ca. 83°, negative, $Bx_a \perp$ cleavage.

IX. Hodrusbánya, Hungary (now Hodruša, Czechoslovakia). B.M. 55371. Extinction straight, 2E medium large, negative.

Epsomite has extinction straight, 2E 78°, negative, $Bx_a \perp$ cleavage.

analysed all the 'fauserites' and pink 'epsomites' in the British Museum collection, with the results set out above (III–IX). Attention to these specimens had been drawn by Miss J. M. Sweet, who while preparing the slip-catalogue of the sulphates had been unable to identify any of the specimens as fauserite. It will be noticed that

TABLE II.

Synthetic study of the system $MgSO_4$–$MnSO_4$–H_2O.

Experiment No.	Weight percentage composition of the Moist Crystals			Solution		
	$MgSO_4$.	$MnSO_4$.	H_2O.	$MgSO_4$.	$MnSO_4$.	H_2O.
1	—	—	—	—	39·1	60·9
2	3·2	59·9	36·9	10·9	34·0	65·8
3	5·1	50·9	44·0	7·7	30·3	62·0
4	15·1	36·8	48·1	7·0	35·2	57·8
5	27·9	21·8	50·3	9·2	26·6	64·2
6	28·5	19·2	52·3	8·1	28·0	63·9
7	31·5	15·9	52·6	9·7	27·3	63·0
8	33·1	12·4	55·5	9·6	25·5	64·9
9	36·8	11·3	51·9	10·5	22·7	66·8
10	36·2	10·3	53·5	11·1	22·5	66·4
11	37·5	9·5	53·0	10·8	21·2	68·0
12	32·2	14·6	53·2	8·2	27·6	64·2
13	43·0	6·9	50·1	11·7	21·2	67·1
14	32·1	11·8	56·1	12·0	19·1	68·9
15	31·5	16·4	52·1	14·9	16·6	68·5
16	42·1	6·0	51·9	13·9	15·1	71·0
17	42·7	3·1	54·2	17·6	9·3	73·1
18	42·8	2·3	54·9	20·1	5·7	74·2
19	—	—	—	25·6	—	74·4

Microscopic examination of the crystals in experiments 1, 2, and 3 showed them to be anorthic, giving extinction-angles up to 15°; they are accordingly the pentahydrate, isomorphous with chalcanthite. Experiments 6 to 19 gave orthorhombic crystals with optic axial angles 2V 50° approximately, negative. From the constancy of this figure it is clear that the admixture of as much as 30 molecules per cent. of $MnSO_4.7H_2O$ has little if any effect on the optic axial angle of epsomite. Experiments 4 and 5 gave mixtures of the anorthic and orthorhombic crystals.

the water content in several cases falls considerably below seven molecules; the specimens in question were definitely somewhat effloresced, and an optical examination showed that the main part of the material was truly an epsomite, the low water being due to the presence of a small portion of kieserite produced by efflorescence. All the specimens correspond more or less to Loczka's in composition, containing cobalt as colouring agent, together with traces of nickel, iron, and zinc, and a variable but small proportion of manganese. In optical properties and specific gravity they agree with epsomite, all showing straight extinction and medium birefringence and having a refractive index in the neighbourhood of 1·45.

While satisfactory in other respects, these analyses throw no light on the real existence or otherwise of Breithaupt's fauserite, with the

TABLE III.

Recalculation of the data on the system $MgSO_4$–$MnSO_4$–H_2O, *in molecular proportions.*

Experiment No.	Moist crystals: Molecular percentage composition			Solution: Molecular percentage composition			Dry crystals: Molecular percentage composition			Molecular ratio $\frac{MgSO_4}{(Mn,Mg)SO_4} \times 100$ for the	
	$MgSO_4$.	$MnSO_4$.	H_2O.	$MgSO_4$.	$MnSO_4$.	H_2O.	$MgSO_4$.	$MnSO_4$.	H_2O.	Solution.	Crystals.
1	—	—	—	—	7·1	92·9	—	16·7	83·3	0·0	0·0
2	1·1	16·8	82·8	1·9	5·1	93·0	0·6	16·1	83·3	26·7	3·6
3	1·5	12·0	86·5	1·7	5·4	92·9	1·4	15·3	83·3	24·3	7·8
4	4·1	8·0	87·9	1·6	6·8	91·6	—	—	—	19·3	—
5	7·3	4·6	88·1	2·0	4·6	93·4	—	—	—	30·2	—
6	7·3	3·9	88·8	1·8	4·9	93·3	8·9	3·6	87·5	26·5	71·2
7	8·0	3·2	88·8	2·2	4·8	93·0	9·8	2·7	87·5	30·8	78·4
8	8·1	2·4	89·5	2·1	4·4	93·5	10·9	1·6	87·5	32·0	87·2
9	9·4	2·3	88·3	2·2	3·8	94·0	10·4	2·1	87·5	36·2	83·2
10	9·0	2·1	88.9	2·4	3·8	93·8	11·0	1·5	87·5	38·2	88·0
11	9·4	1·9	88·7	2·2	3·5	94·3	10·7	1·8	87·5	39·1	85·6
12	8·1	2·9	89·0	1·8	4·6	93·6	10·1	2·4	87·5	39·2	80·8
13	11·2	1·4	87·4	2·5	3·6	93·9	11·1	1·4	87·5	40·9	89·2
14	7·7	2·3	90·0	2·5	3·1	94·4	10·9	1·6	87·5	44·2	87·2
15	8·0	3·3	88·7	3·1	2·7	94·2	9·0	3·5	87·5	52·9	72·4
16	10·7	1·2	88·1	2·8	2·4	94·8	11·4	1·1	87·5	53·8	91·2
17	10·5	0·6	88·9	3·4	1·5	95·1	12·2	0·3	87·5	69·9	97·6
18	10·4	0·5	89·1	3·9	0·9	95·2	12·3	0·2	87·5	81·4	98·0
19	—	—	—	4·9	—	95·1	12·5	—	87·5	100·0	100·0

ratio $MgSO_4/(Mn,Mg)SO_4$ about 33 %. Recourse was therefore had to synthetic experiments, in the hope of finding conditions under which such material could crystallize. If these conditions were such as might reasonably be expected in nature, it would appear reasonable to conclude that Breithaupt's results were correct, and fauserite would stand as a reasonably well-established, but rare species. Unfortunately, the results were not quite so definite as had been hoped; although the evidence is very strong for the view that Mollnár's analysis was made on a mixture, and that Breithaupt's crystals did not contain more than 30 to 40 % of $MnSO_4.7H_2O$, the matter is still open to some doubt.

The synthetic experiments were of a very simple nature but gave fairly satisfactory results. A number of mixtures of magnesium and manganese sulphates were dissolved in a little water at a gentle heat and allowed to stand in corked tubes in a cool corner of the laboratory for five months to attain equilibrium; the temperature was about

17–19° C. throughout. Then the crystals were filtered off, and the mother-liquor analysed; to avoid errors introduced by attempts at drying, the moist crystals were analysed,[1] after pressing out most of the mother-liquor between filter-paper. The composition of the crystals without the adherent mother-liquor is then arrived at by a slight modification of Schreinemaker's method. In fig. 1, *L* is the composition of the mother-liquor in one experiment and *M* the composition of the moist crystals deposited therefrom. The composition of the crystals themselves must lie somewhere along the line *LM* extended. Since microscopic examination showed that the crystals were homogeneous and isomorphous with epsomite, we are justified in assuming that their composition must also be represented by a point along the line *El*, which represents $(Mn,Mg)SO_4.7H_2O$. Therefore the composition of the crystals is given by the point *C*, at the intersection of *LM* and *El*. This method cannot, of course, be directly applied to the eutectic *P*, the precise composition of the heterogeneous mixture of crystals deposited here remaining uncertain; but this is of no importance, as the composition of the mixture is of no interest.[2]

In this way we are able to plot the solubility curves of the system $MnSO_4$–$MgSO_4$–H_2O at 17–19° C. (fig. 1), from the analytical data of table II. We see that manganous sulphate solutions containing up to about 25 % of magnesium sulphate (in molecular parts, $MgSO_4 \times 100/(Mn,Mg)SO_4$) deposit at this temperature crystals of $(Mn,Mg)SO_4 5H_2O$, isomorphous with chalcanthite, and containing a much smaller proportion of magnesium than the solution (about 6 % in the maximum). More magnesium-rich solutions deposit

[1] The analyses were performed by Mr. S. E. Ellis of the Mineral Department, the method used being as follows: a portion of the solution or moist crystals was weighed out, diluted to 250 c.c., and an aliquot part taken for the estimation of sulphate as $BaSO_4$. In a second portion ($MnO+MgO$) was estimated as the mixed pyrophosphates, while a third served for the manganese estimation. In the manganese-rich solutions and crystals this was carried out gravimetrically, the manganese being precipitated as sulphide and converted to pyrophosphate, but when more magnesium was present, the volumetric determination of manganese by Volhard's method, with $KMnO_4$ and zinc acetate, was employed. Water was obtained by difference.

[2] The composition of the eutectic mixture could be found if desired, but is of no value. If in fig. 1 *l* and *l′* (derived from fig. 2) be the compositions of the two mixed crystals involved in the eutectic, the composition of the mixture must lie along *ll′*, and is given by the point at which the tie-line joining the compositions of solution and moist crystals cuts *ll′*.

$(Mg,Mn)SO_4.7H_2O$, isomorphous with epsomite, and containing a much higher proportion of magnesium than the solution (70 % in the minimum). The eutectic solution has a composition about H_2O 92·6 mols., $MgSO_4$ 1·85 mols., $MnSO_4$ 5·55 mols.; or H_2O 61·1 %, $MgSO_4$ 8·2 %, $MnSO_4$ 30·7 %. Fig. 1 really gives a com-

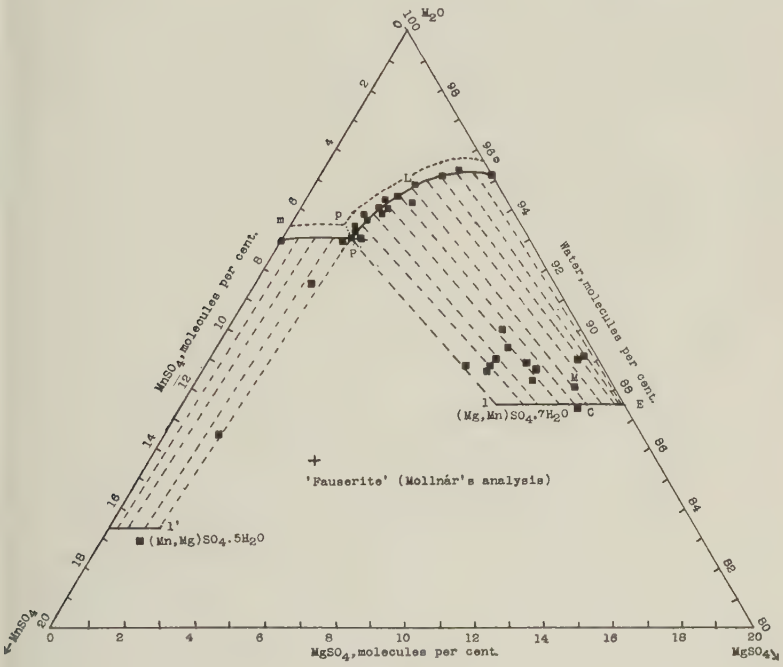


Fig. 1.

plete account of the system,[1] but the relation between the proportion of the two salts in the solution and in the crystals will be better understood from fig. 2, where they are directly plotted.

We now see that a homogeneous crystalline phase of the composition of Breithaupt's fauserite could not be deposited from a solution of magnesium and manganese sulphates at 17–19° C. Two possibilities now arise. Either Mollnár's analysis was made on heterogeneous material, consisting of a mixture of $(Mn,Mg)SO_4.7H_2O$,

[1] The dotted tie-lines (e.g. *LMC*) in fig. 1 are drawn in by the aid of the smoothed curve of fig. 2, the actual tie-lines between the analyses of liquid and crystals being omitted for clarity.

and $(Mn,Mg)SO_4.5H_2O$—a possibility supported by the low water content, or the deposition may have occurred at a different temperature, at which the relations might be different.[1] Let us consider this second possibility. The dotted curves *ep* and *mp* in fig. 1 trace the probable course of the solubility curves at 9° C., being based on the known solubilities (*e* and *m*) of $MnSO_4.5H_2O$ and $MgSO_4.7H_2O$ at that temperature and the fact that the curves usually tend to move parallel with themselves on change of temperature. The line *Pp* will then trace the probable change of the eutectic with temperature from 17° to 9° C. Now change of temperature does not usually affect the relation between the proportions of the two salts in the mixed crystal and in the solution very much; therefore, we may reasonably extend the $(Mg,Mn)SO_4.7H_2O$ curve of fig. 2, to about *u* for a temperature of 9° C., or perhaps to about *u'* for 0° C. But even then there is no sign of any approach to the point *F*, which would correspond to deposition of crystals of the composition given by Mollnár's analysis (apart from the water content).

Thus we are led to conclude that Mollnár's analysis was made on a heterogeneous eutectic mixture of $(Mn,Mg)SO_4.5H_2O$, and $(Mg,Mn)SO_4.7H_2O$; while Breithaupt's orthorhombic crystals (which were undoubtedly isomorphous with epsomite[2] and hence had $7H_2O$) were probably not richer in manganese than between 30 and 40 mols. % $MnSO_4.7H_2O$. It is perhaps additional confirmation to note that if we assume Mollnár's analysis to be accurate and the pentahydrate to have contained 5 mols. % of $MgSO_4.5H_2O$, the mixture works out at 57 parts of this hydrate to 43 parts of $(Mg,Mn)SO_4.7H_2O$, containing 33 mols. % $MnSO_4.7H_2O$—a eutectic which might clearly have been deposited at a temperature a little lower than 17–19° C.

It may be noted that the system $MgSO_4$–$MnSO_4$–H_2O was studied

[1] The analysis is stated to have been made on clear crystals, which makes it improbable that the low water was due to efflorescence. On the other hand, the crystals might well have been a mixture, since it is unlikely that the best developed material would be used, and the author has observed that crystals of $(Mg,Mn)SO_4.7H_2O$ and $(Mn,Mg)SO_4.5H_2O$ are not readily distinguished unless well developed or unless optical examination is resorted to. There is a third but unlikely possibility; the analysed crystals may have really been a hexahydrate, since monoclinic and tetragonal series of hexahydrates are known among the vitriols. But Breithaupt's measurements cannot be reconciled with either series.

[2] Epsomite is orthorhombic and has the *b*-cleavage, $mm''' = 89° 26'$ (fauserite 88° 42').

by C. F. Rammelsberg,[1] who found that crystals deposited at the ordinary temperature containing up to 43 mols. % $MnSO_4$ had the epsomite form, in fair agreement with the present results. But

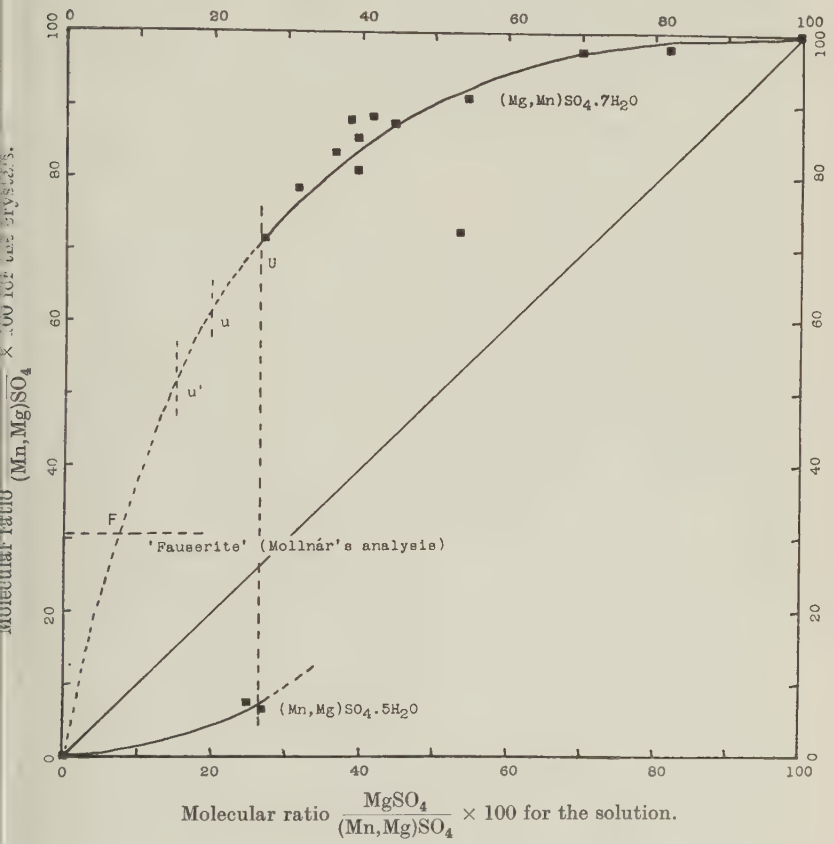


FIG. 2.

the more manganese-rich crystals he found to be a heptahydrate isomorphous with melanterite and containing up to 34 mols. % $MgSO_4$; this was perhaps a metastable equilibrium, which readily occurs with manganous sulphate; moreover, below 9° C. manganous sulphate heptahydrate is stable and is monoclinic and isomorphous with melanterite. R. Hollmann,[2] on the other hand, found a well-

[1] C. F. Rammelsberg, Ann. Phys. Chem. (Poggendorff), 1854, vol. 91, p. 342.
[2] R. Hollmann, Zeits. Physik. Chem., 1901, vol. 37, p. 209 (footnote 4).

defined series of triclinic mixed crystals, 'probably a pentahydrate', but he gives no quantitative data. R. Balló [1] does not appear to have examined his solid phases for homogeneity, and believed he had discovered a series of mixed crystals of $MgSO_4.7H_2O$ and $MnSO_4.5H_2O$, so that his results are practically useless. However, the supposed solubility minimum, at which crystals and solution contain the two salts in the same proportion, and to which continued evaporation led, must have been the eutectic; he found it to lie at 19·5 mols. % $MgSO_4$, at 18–21° C., in moderately good agreement with the present result. His conclusions with regard to fauserite are, of course, worthless.

With regard to the application of the name fauserite, it seems undesirable to associate it with the mixture analysed by Mollnár, and it is suggested that it be retained for manganiferous epsomites containing a considerable proportion of manganese, such as the crystals studied by Breithaupt which would be the richest possible in manganese. On the high magnesium side, no precise limit to the variety can be suggested, but it appears reasonable to regard analysis VII (B.M. 44274) with 15 mols. % $MnSO_4$ as a fauserite. The case is parallel to that of melanterite, pisanite, and chalcanthite studied by H. F. Collins [2]; melanterite corresponds to epsomite, fauserite to pisanite, and $MnSO_4.5H_2O$ (not known in nature) to chalcanthite. The stalactitic 'fauserite' analysed by Mollnár would correspond to a 'pisanite' containing over 19 % CuO and really consisting of a mixture of pisanite and chalcanthite (compare H. F. Collins, loc. cit., p. 37).

If the above interpretation of the data of Breithaupt and Mollnár is correct, the material analysed by the latter must have contained about 57 % of $(Mn,Mg)SO_4.5H_2O$, hitherto unrecorded as a mineral. The selection of a name for this new member of the chalcanthite group had, however, best await the definite confirmation of its ocurrence and physical properties.

[1] R. Balló [Magyar Chem. Folyóirat, 1907, vol. 13, pp. 17, 33, 49, 65, 81, and 97]; abstr. in Zeits. Kryst. Min., 1910, vol. 47, p. 298.

[2] H. F. Collins, Min. Mag., 1923, vol. 20, p. 32.

On a new method of detecting pyro-electricity.

By A. J. P. Martin,
Exhibitioner of Peterhouse, Cambridge.

[Read March 17, 1931; communicated by Dr. W. A. Wooster.]

Introduction.—Pyro-electricity has been investigated by various methods. Sir David Brewster[1] heated his crystals and brought them into contact with small, very light, insulating particles. If these adhered, the presence of pyro-electricity in the crystal was inferred. He also used a very delicately suspended brass needle. Being a conductor it was attracted to a charged crystal when this was brought near to it. Hankel[2] placed the crystal under investigation in a small bath of copper or iron filings, which was then put into a hot-air oven. The filings did not entirely cover the whole crystal, but one corner, edge, or face, whichever was required, was left exposed. A very small platinum sphere connected to an electrometer was then brought near to the exposed portion. The charge induced on the sphere was taken as a measure of the charge developed at the particular spot on the crystal opposite the platinum sphere. Gaugain[3] attempted to make quantitative measurements by placing on the charged crystal a small hemispherical brass block connected to an electrometer which flicked and discharged itself whenever the potential rose to a certain value. The number of discharges occurring during the cooling of the crystal measured the total charge developed. Kundt[4] sprinkled a composite powder of two differently coloured, and oppositely charged constituents, over the crystal. The separation of the coloured powders and their position on the crystal indicated the presence and distribution of pyro-electricity. More recently, Hettich and Schleede[5] have developed a probe method. A small platinum point supported by an insulating handle is gently brought into contact with different

[1] D. Brewster, Edinburgh Journ. Sci., 1824, vol. 1, p. 208.
[2] W. G. Hankel, Abhandl. K. Sächs. Gesell. Wiss., 1859, vol. 4, p. 149.
[3] F. M. Gaugain, Compt. Rend. Acad. Sci. Paris, 1856, vol. 43, p. 916.
[4] A. Kundt, Sitzungsber. Akad. Wiss. Berlin, 1883, p. 421.
[5] A. Hettich and A. Schleede, Zeits. Physik, 1928, vol. 50, p. 249.

parts of the cooling crystal, and the charge induced on the platinum point is amplified and recorded by a galvanometer, the whole arrangement being very sensitive because of the use of modern electrometer-valves and valve-amplifiers. Meissner[1] has also investigated powdered crystals by placing them in a shallow layer between two plates a centimetre or so apart maintained at a difference of potential of about 8,000 volts. On heating and tapping the powder, the crystals, if pyro-electric, orientate themselves, so that on cooling a strong charge is induced on one of the plates if it is insulated and the other is earthed. The ice crystals which develop on a crystal hung in moist air after it has been cooled in liquid air may also be used to detect and investigate pyro-electricity.[2]

The method presented here is simple and probably as sensitive as any used previously. It has two advantages because low temperatures are used; the crystals are not decomposed and the insulation of all crystals which are not metallic is increased by cooling. Further, the experimental conditions are more definite than is usually the case, in that the crystal is at the same temperature at every point during the experiment.

The importance of pyro-electricity is the help it gives in the determination of space-groups. Pyro-electricity is of two kinds, 'true' and 'false'. 'False' pyro-electricity is the piezo-electric charge developed by the thermal deformation consequent on heating or cooling, and occurs in any crystal lacking a centre of symmetry. 'True' pyro-electricity is a theoretical conception which could only arise in crystals possessing a single polar axis, but in fact it has never been unambiguously demonstrated. Since in this experiment the crystal arrives at the same temperature throughout, the deformation may be considered homogeneous and only those crystals possessing a single polar axis can show any effect.

Experimental Method.—The apparatus (fig. 1) consists of a Dewar flask with an unsilvered strip, containing liquid air, in which is immersed a metal plate A supported on a glass rod which is pivoted at C. By employing a sufficiently long handle F, it is possible to move A a very small distance with certainty. Opposite the plate A, the crystal to be tested, B, is suspended by a glass fibre D, to which it is attached by a loop of cotton or, in the case of very small crystals, by Kodak mounting paste. At the other end, the glass fibre is carried

[1] A. Meissner, Die Naturwissenschaften, 1929, vol. 17, p. 25.

[2] M. E. Maurice, Proc. Cambridge Phil. Soc., 1930, vol. 26, p. 491.

by a hook attached to a rotatable head (a cork carrying a glass rod), so that the orientation of the crystal to the plate may be varied.

The procedure is as follows. The crystal, mounted as described, is lowered gently into the liquid air, and, after ebullition has ceased,

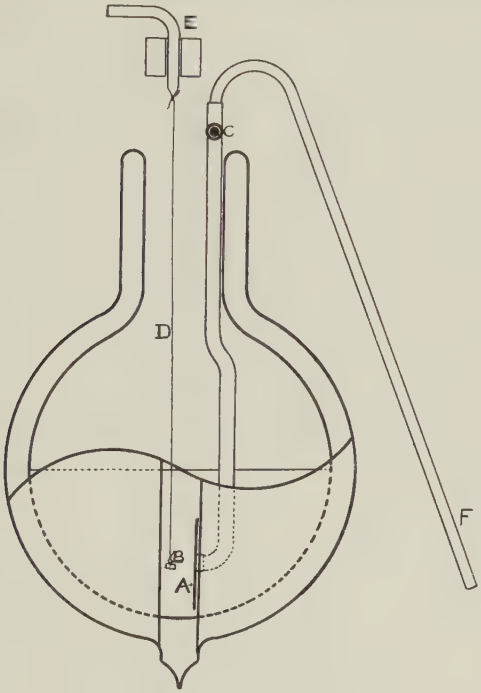


Fig. 1. Dewar flask with arrangement for detecting pyro-electricity. (The lower half of the figure represents an actual side-view of the apparatus whilst the part above the wavy line is a sectional view.)

the metal plate is moved towards the crystal very slowly. A pyro-electric crystal is attracted towards the plate by the induced charge, and clings to the plate as the latter is withdrawn. Tourmaline and rochelle salt adhere so vigorously that it is difficult or impossible to shake them off.

The position of the electric axis may in general be found by rotating the crystal and finding which part adheres most strongly: this is the end of the electric axis.

Because of the low temperature the rate of loss of charge is generally very slow (tourmaline retains much of its charge after half an hour), and observations may be repeated many times before it becomes necessary to withdraw the crystal and allow it to warm up again.

Crystals of more or less cubical shape, with sides from one centimetre to one millimetre, may conveniently be employed, or needles or plates 0·1 mm. thick, provided the electric axis be parallel to the length of the needle or to the plane of the plate.

Results.—The investigation was started in order to test thomsonite, nepheline, and dioptase for pyro-electricity. All of these showed the effect, six crystals of dioptase being investigated. It is remarkable that in text-books dioptase is usually given as the typical member of the rhombohedral class of the trigonal system, and should therefore possess a centre of symmetry. It appears from this work that dioptase cannot belong to the same class as phenakite, willemite, dolomite, pyrosmalite, and ilmenite, none of which showed any trace of pyro-electricity when tested by this method.

The statement about dioptase is not new, as Hankel [1] investigated eight crystals and found three of them negative at both ends on cooling, and positive in the middle, whilst the other five were positive at one end and negative at the other.

Boracite, struvite, axinite, prehnite, scolecite, and asparagine all showed a positive effect. Among crystals possessing more than one electric axis, quartz, cinnabar, epsomite, barium nitrate, and zinc-blende were tried and showed no effect. It is to be noted that boracite is not cubic at ordinary temperatures.

In suggesting a new method of investigating a phenomenon it is desirable to compare it with other methods. The powder method of Kundt is suitable only for substances which have a fairly strong effect and occur as crystals larger than 3 mm. cube. The electrometer methods of Hankel and Gaugain can be applied only to fairly large crystals; and although the writer has no experience of Meissner's probe method, he considers it of doubtful value with crystals less than 3 mm. cube. Meissner's orientation method is suitable for fine powders, but the apparatus is relatively complicated. The piezo-electric method of Giebe and Scheibe,[2] in which small crystal grains are made to execute very high frequency mechanical vibrations by means of a valve-oscillator, is especially applicable to small crystals

[1] W. G. Hankel, Abhandl. K. Sächs. Gesell. Wiss., 1883, vol. 12, p. 549.

[2] E. Giebe and A. Scheibe, Zeits. Physik, 1925, vol. 33, p. 760.

(less than 3 mm. cube), but a weak effect is very difficult to detect. The method presented here is generally unable to detect any effect if more than one electric axis be present. This limitation is not present in some of the other methods mentioned, and the present method and that of Giebe and Scheibe should be regarded as complementary, and should both be employed in detecting the absence of a centre of symmetry.

Summary.—1. A new experimental method of detecting pyro-electricity is given, which depends on the attraction between a charged crystal and a metallic conductor, the charge being developed by cooling the crystal in liquid air.

2. Results for a number of crystals are given, attention being drawn to dioptase, which although placed in a centro-symmetrical class, yet shows definite pyro-electricity.

3. A comparison is made between this and other methods.

My thanks are due to Prof. A. Hutchinson for the loan of the crystals, to the Cavendish Laboratory for the Dewar flask and the liquid air, and to Dr. W. A. Wooster for his continual help and advice.

Clouded felspars and thermal metamorphism.

By A. G. MacGregor, M.C., B.Sc.
Geological Survey of Scotland.

[Read by Dr. H. H. Thomas, F.R.S., March 17, 1931.]

THE present paper summarizes the facts at present known regarding a characteristic effect that is often produced in the fresh plagioclase felspars of igneous rocks by thermal metamorphism—namely the development of a special type of cloudiness caused by the appearance of minute inclusions. Reference is also made to certain well-known rocks in which the clouding of plagioclase felspars has been described without any suggestion that the peculiarity of the felspars is connected with thermal metamorphism.

Clouded Felspars in Contact-Metamorphosed Lavas and Minor Intrusions.

Teall seems to have been the first to connect with contact-metamorphism the presence in plagioclase phenocrysts of cloudiness of a peculiar and special type (1888, pp. 279, 280).[1] The cloudy appearance was caused by the presence of innumerable minute inclusions. Teall studied their mode of occurrence in considerable detail, and pointed out their close resemblance to the minute inclusions in the clouded felspars of the Baltimore gabbro, described and figured by Williams (1886).

Eleven years later, in 1899, Kynaston read before the Edinburgh Geological Society a paper—not published until 1905—in which he showed that Teall's suggestion was correct (1905, pp. 18, 20, 24). He found that the same peculiar cloudiness was a characteristic feature produced by contact-metamorphism, due to the Cheviot granite, in the plagioclase phenocrysts of andesite lavas of Lower Old Red Sandstone age. Shortly afterwards Kynaston found that similar cloudiness had been produced in the plagioclase phenocrysts

[1] The references in brackets refer to the bibliography given on p. 537.

of andesite lavas in Glen Etive, as one effect of the intrusion of the Cruachan granite (1901, p. 83). Bailey (1916, pp. 204–209), besides confirming Kynaston's results, found that clouding of similar type in porphyritic plagioclase felspars is a feature of other lavas, and of various intrusions (mainly dikes), in the Glen Coe district, and is quite definitely due to contact-metamorphism. Tyrrell (1916, p. 544) appears to have observed the same phenomenon in the plagioclase phenocrysts of hornfelsed porphyries from Benguella. He made no comment, however, on the significance of the dust-like inclusions that gave the felspars a bluish tinge.

More recently, the writer has found that the development of this peculiar cloudiness in plagioclase felspars is a feature of certain contact-metamorphosed minor intrusions in Ayrshire (MacGregor, 1930, pp. 35–38, 50) and in Aberdeenshire (MacGregor, 1929, p. 553). It is convenient at this point to give a statement of the writer's Ayrshire results, for the account applies generally to all clouded plagioclase felspars that have been examined in the course of the preparation of this paper. It should be understood at the outset that the peculiar cloudiness of the felspars of contact-metamorphosed igneous rocks is in appearance quite different from any kind of turbidity due to decomposition.

In the Ayrshire dikes and sills the clouding is seen in plagioclase phenocrysts (andesine or labradorite) and sometimes in groundmass plagioclase laths as small as $0{\cdot}25 \times 0{\cdot}06$ mm. The contact-metamorphism may be severe enough to form hornblende and biotite from chlorite, and yet produce no effect on the plagioclase felspars (cf. p. 529). Cloudiness is not invariably found in the felspars of the more highly metamorphosed dikes. In fact in a single slice some crystals may show the feature well, and others poorly or not at all.

The phenomenon takes the form of faintly-brown patches due to almost ultra-microscopic specks, or of a general or localized (patchy) grey cloudiness due to the concentration of extremely minute opaque inclusions. The latter, under a $\frac{1}{4}$-inch objective or higher powers, may in some cases just be seen to consist of both (1) equidimensional specks, and (2) very short rod-like forms. The rods tend to occur in parallel sets (probably along crystallographic planes), and the equidimensional specks are interspersed among them. Sets of these minute inclusions occur at different levels even in the thickness of a normal rock section. Sometimes there is little apparent regularity in the distribution of the dark specks. Quite often, however, there

is a tendency to streaky development, especially along the junctions of multiple-twinning lamellae. Very occasionally longer hair-like rods (up to 0·05 mm.) accompany the very minute particles.

The inclusions occur in perfectly fresh plagioclase in which the original twinning and very marked zoning appear quite unaffected. Where part of a felspar was decomposed before metamorphism the clouding is only seen clearly in the originally fresh and limpid felspar substance. The originally decomposed portions remain clearly distinguishable, even in the most severely metamorphosed rocks. The least basic (outermost) parts of zoned crystals do not as a rule become clouded, nor do those portions of the more basic interior that may have been replaced by albitic felspar before metamorphism.

The cloudiness is not seen in any of the numerous sliced minor intrusions that occur outside the metamorphic aureole of the Ayrshire granodiorite-diorite complex, and within the aureole it appears only in the more intensely altered rocks.

The inclusions look more like iron-ore than anything else, for even with a high-power objective they appear to be opaque in most cases (cf. Rosenbusch, 1907, pp. 323, 324). In some cases, however, it is not quite certain whether this is because the particles and hair-like rods are too small for the resolving power of the microscope.[1] The writer was unable to decide whether the inclusions owe their origin to pneumatolytic effects, or to purely thermal effects within the felspars. It is clear, however, that these inclusions arise in perfectly fresh plagioclase; that soda-rich plagioclase is unfavourable to their formation; and that apart from the cloudiness due to their presence the zoned and twinned felspar crystals appear quite unchanged after the inclusions have developed. The felspar phenocrysts are stable even in rocks that are found at a plutonic contact and that have suffered groundmass granulitization.

Kynaston found at Cheviot and in Glen Etive that clouded felspars in the lavas show a marked stability and usually maintain their individuality as phenocrysts[2] even at the actual granite contact, although outer margins against the recrystallized groundmass may become ragged (cf. Thomas and Bailey, 1924, p. 154). Bailey made

[1] Dr. T. Robertson and the writer have recently found evidence suggesting that rutile needles are present in certain clouded felspars.

[2] The writer has confirmed this. In the Survey Collection from Glen Coe no fresh phenocryst is recrystallized.

the suggestion that the cloudy felspars of the Glen Etive and Glen Coe region had been partly decomposed to albite with minute inclusions of zoisite and epidote before the intrusion of the granite, and that the heat of the intrusion regenerated basic plagioclase, with indefinable residual products, from the mixture (1916, pp. 205, 208, 209). After reconsidering the whole question in the light of the Ayrshire evidence Bailey[1] has come to the conclusion that the hypothesis of the Glen Coe Memoir must be abandoned. He agrees that the peculiar cloudiness is produced in perfectly fresh felspars by contact-metamorphism, and that the phenomenon is not a sign of the regeneration of decomposed felspar.

Clouded Felspars in Certain Odenwald Dike-Rocks: *e.g.* Malchite.

While dealing with the significance of clouded felspars in porphyritic rocks it seems desirable to discuss briefly a well-known rock-type from the Odenwald in Germany.

When working out a classification for the north Ayrshire dikes, the writer, along with Prof. E. B. Bailey, examined a suite of slices of Odenwald dikes for comparative purposes. Prof. Bailey, who was familiar with the contact-metamorphosed dikes and lavas of the Glen Coe region, pointed out that the slice representing malchite showed many of the peculiarities of the baked Scottish rocks. This was also found to apply to others, such as alsbachite. One of these features was the characteristic clouding of larger plagioclase felspars in the malchite. The writer agreed with Prof. Bailey that the evidence for the thermal metamorphism of the malchite dike (the type rock from Melibocus) appeared to be quite conclusive. In consequence, it appeared undesirable to continue to apply the name 'malchite' to unmetamorphosed dike-rocks of similar chemical and mineralogical composition, but of normal igneous structure.

More recently the writer has examined a number of other slices of Odenwald dikes sent to this country at various dates by Krantz, or Voigt and Hochgesang. Plagioclase felspars showing the clouding typical of contact-metamorphism are present in slices labelled 'Malchite, middle of dike, Zwingenberg, Bergstrasse,' and 'Orbite, summit of Melibocus, Odenwald'; moreover there has been considerable recrystallization in the groundmass of both specimens.

[1] Personal communication.

There is little in the present interpretation of the geological history of the Odenwald[1] to account for the postulated contact-metamorphism of the Melibocus malchite. It seems possible, however, that the complicated igneous and metamorphic history of the Odenwald is not yet fully known. For many years it was believed that the beerbachites, gabbro-porphyrites, and gabbro-pegmatites of Chelius were, as he asserted, dike-rocks cutting the Odenwald gabbro. It is only recently that Klemm has shown that these rocks are in reality hornfelsed inclusions in the gabbro.[2]

The Clouded Felspars of the Scourie Dikes and of Certain Metadolerites.

The illustrations of the micro-sections of the metamorphosed dikes of the Scourie district in Sutherland, published in Teall's 'British Petrography' (1888, plates XIX, XX) and in the Geological Survey Memoir on the north-west Highlands (1907, plate XLVII, fig. 2), suggested to the writer that the plagioclase felspars of these rocks contain clouds of inclusions similar to those that have been under consideration. On examining slices mentioned by number in the north-west Highland Memoir, it was found that clouding of the same type is to be seen in the Ayrshire contact-metamorphosed dikes.

In several of the Scourie slices clouding is of the ultra-fine brown variety. This is often accompanied by grey clouding due to very minute rods and specks, or in many cases to specks and longer hair-like rods (rarely exceeding 0·05 mm. as seen in rock slices).

In one of the unsheared Scourie slices (3043)[3] anhedral quartz, wedged between the felspar laths, locally shows ultra-fine brown clouding as well as part of the plagioclase. The latter has, in addition, grey clouding due in part to delicate hair-like rods. Several of these hairs cross the felspar-quartz junction, one half being embedded in felspar and the other half in quartz. This seems to show that the delicate hair-like inclusions developed after the

[1] G. Klemm, Notizblatt des Vereins für Erdkunde und der Grossherz. Landesanstalt zu Darmstadt, 1910, IV Folge, Heft 31, pp. 21, 25; and op. cit., 1926, V Folge, Heft 9, pp. 104, 107–111; also G. Klemm, Führer bei geologischen Excursionen im Odenwald, Berlin, 1910, pp. 11–67; and G. Klemm, Geologische Übersichtskarte des Odenwaldes, second edition, 1929; and Beda Sandkühler, Abhandl. der Grossherz. Hessischen Geol. Landesanstalt zu Darmstadt, 1913, Band V, Heft 3, pp. 201–211, 214–219, 222.

[2] G. Klemm, op. cit., 1926, pp. 111–115.

[3] No. of slice in Scottish Collection of H.M. Geological Survey.

consolidation of the felspar and quartz. Very sparse short little rods are wholly embedded in quartz. The quartz seems free from clouding or inclusions in a number of the slices with well-clouded felspar.

Teall originally considered that the dikes had been metamorphosed under high pressure at ordinary temperature (1885, p. 141). In later years, however, he thought that the temperature may have been not far below that of actual fusion (1918, p. 6). The peculiar clouding of the plagioclase felspars of the massive portions of the dikes did not escape the notice of Teall (1888, p. 198, and explanation of plate XIX; also 1907, p. 90). He also recorded similar inclusions in the olivines and augites of the dikes, but not in all three minerals in one and the same rock, and expressed the opinion that possibly they are original products of the magma.

Teall made important observations in those parts of the dikes showing incipient alteration to hornblende-schist. In these rocks he found that the plagioclase is partly cloudy and partly colourless. The cloudy portions often preserve more or less the form of the original felspars, whereas the newly crystallized felspar developed under dynamic metamorphism is quite clear. In the thoroughly schistose rocks, in which recrystallization is complete, the felspar no longer shows the peculiar clouding (Teall, 1888, pp. 199, 200, and explanations of plates XIX, XX, XXI). Teall's observations also show that parts of the Scourie dikes have been converted by metamorphism into hornblende-plagioclase-rocks *without foliation*. Where original igneous structure is still recognizable in such rocks clouding of the relict labradorite laths, as Teall pointed out, is still to be seen. Where complete recrystallization has obliterated igneous structure Teall observed, however, that the recrystallized felspar is not clouded and tends to be more albitic.

In this connexion attention must be called to certain general results of the writer's work on the metamorphism of igneous rocks in normal contact-aureoles. When contact-metamorphism has been so severe as to render original plagioclase unstable, so that it loses its original form and recrystallizes, *such newly formed felspar is not clouded*. Recrystallization of original *fresh* labradorite usually takes place in contact-aureoles under physico-chemical conditions that result in the formation of pyroxenes at the expense of hornblende. In contact-aureoles, plagioclase-clouding represents a grade of metamorphism lower than that at which original fresh labradorite

becomes unstable and recrystallizes; and under these lower grade conditions biotite or hornblende, not pyroxene, is often formed (MacGregor, 1930, pp. 35–38). *Large* fresh plagioclase felspars, however, often remain stable in rocks in which very advanced or complete granulitization has taken place at the expense of the groundmass constituents.

The writer would suggest that the peculiar clouding of the felspars of the Scourie dikes is due to the fact that after—probably long after—the intrusions had completely consolidated, they were very considerably heated up again. This reheating of the dikes was followed at a later stage by metamorphism under different physico-chemical conditions. Earth movements were going on during the recrystallization produced by this phase of metamorphism, and brought about local foliation. The felspars became clouded, but remained stable, during the preliminary phase of thermal metamorphism unaccompanied by appreciable shearing stress. The subsequent dynamo-thermal metamorphism, in which water in some form perhaps played an important part, gradually broke down the original minerals, and the felspar that recrystallized was unclouded. Whether the thermal metamorphism that produced the clouding was caused by regional heating connected with depth, or was brought about mainly by the heat of neighbouring igneous magma, is not a matter on which the writer cares to express an opinion at the present time.

It may be mentioned here that during research work on the Dalradian schists in Glen Clunie, Aberdeenshire, the writer has recently found a small fine-grained epidiorite sill or sills that show phenomena closely similar to those of the Scourie dikes, and on which he puts a similar interpretation. In places the original fresh felspar-plexus of the dolerite is preserved, although all original pyroxenes have disappeared and are now represented by aggregates consisting mainly of pale green hornblende. These relict felspars are zoned labradorite, and under low powers show greyish clouding. Under high powers the cloudy effect is seen to be partly, perhaps largely, produced by minute apparently opaque specks and tiny rods, but in addition there are present in some instances numerous larger, but still very minute, needles, prisms, and grains of a transparent mineral with a refractive index that is high with relation to the enclosing felspar. As far as optical properties can be made out in such minute crystals they seem identical with those of the very pale hornblende that in places extends into the felspar laths along cracks. The minute

doubly-refracting needles and prisms are often arranged in parallelism. In other slices, dynamic metamorphism has completely obliterated igneous structures and the felspar is recrystallized. The granular recrystallized felspar is unclouded.

This epidiorite is mentioned because the doubly-refracting nature of some of the inclusions make possible a comparison with Australian metadolerites described by Tilley (1921, pp. 75–131). The latter are probably dike-rocks entangled in later acid gneisses, and thermally metamorphosed by them. The zoned labradorite crystals are crowded with minute black or dark dust that renders them semi-transparent. These minute inclusions were regarded by Tilley as probably composed of pyroxene, and he apparently thought they were an original feature of the felspars. To the writer it seems more probable that the clouding was caused by thermal metamorphism.

Clouded Felspars in Certain Plutonic Rocks.

Clouding of plagioclase in plutonic rocks—notably gabbros and hyperites—has often been described, but until recently no definite suggestion has been put forward that the phenomenon is a result of thermal metamorphism.

Last year the writer brought forward evidence to show that clouding in the felspars of certain dioritic rocks of north Ayrshire has been produced by contact-metamorphism due to a later intrusion (MacGregor, 1930, pp. 39–52). Some of these north Ayrshire rocks are indistinguishable from 'hyperites' described by Teall from the Southern Uplands of Scotland (Teall, 1899, pp. 612–615), and the writer suggested that the latter are also contact-metamorphosed, having been thermally altered by the adjacent granodioritic rocks.

In the Geological Survey Memoir on Ardnamurchan, Richey and Thomas deal with the clouded felspars of gabbros, eucrites, and dolerites, and they have come independently to much the same conclusions as those at which the writer arrived in Ayrshire.

The present discussion will be limited to the Ayrshire dioritic rocks, the Tertiary Igneous Complex of Ardnamurchan, and the Baltimore gabbro and Swedish hyperites cited by Teall as directly comparable with rocks which, according to the writer, show evidence of thermal metamorphism.

Dioritic rocks of north Ayrshire.

The writer's Ayrshire results may be summarized as follows. The cloudiness in the plagioclase felspars of some of the dioritic rocks is

exactly similar to that found in the more highly contact-metamorphosed dikes and sills (p. 525). Other evidence (e.g. the presence of a contact-metamorphosed dike cutting one exposure of dioritic rocks; the occurrence of hornblende-filled veinlets traversing the felspars) shows that these plutonic rocks have been affected by thermal metamorphism after their consolidation. The plutonic rocks cut and bake sandstones of Downtonian and Lower Old Red Sandstone age. It was therefore concluded that the clouding in their felspars is due to contact-metamorphism produced by the local granodiorite.

Pronounced grey cloudiness in the plagioclase felspars of other slices of the contact-altered dioritic rocks is, however, seen to be due to the presence of innumerable inclusions which, though very minute, are individually larger than those which produce the grey cloudiness in the dikes and sills. These relatively larger inclusions also consist of little apparently opaque grains and relatively short rods, and occasionally of longer hair-like rods arranged in parallel sets. The latter type of clouding is also seen in some of the slices of the granodiorite that is supposed to have effected the thermal metamorphism of the dioritic rocks.

As there seems to be every transition from the ultra-fine clouding due to indeterminate specks, through cloudiness due to minute specks and tiny rods, to that due to longer hair-like rods, the conclusion was arrived at that all varieties of clouding owe their origin to thermal or pneumatolytic metamorphic effects.

The cloudiness in those granodiorite slices that show it is much less pronounced than in most of the dioritic rocks or in the dikes and sills. It was suggested that in the granodiorite the phenomenon may be due to late auto-pneumatolytic effects, or more probably to a later intrusion of granodiorite having affected an earlier one. There is some local evidence to support the latter hypothesis.

In the last paragraph we come to the main difficulty in dealing with the significance of clouded felspars in plutonic rocks. If we have evidence to show that the felspar-clouding is not an original feature of the crystallization period, can we decide whether it is (1) the result of late auto-pneumatolytic, or deuteric, effects, or (2) the result of post-consolidation thermal metamorphism due to an external cause? The observations of Richey and Thomas in Ardnamurchan throw a good deal of light on this problem, and will now be considered.

The Tertiary gabbroic rocks of Ardnamurchan.

The phenomenon described in this paper as 'cloudiness' in felspars is the same as that referred to in the Ardnamurchan Memoir in some places as 'cloudiness' but usually as 'turbidity and schillerization'. The writer has examined the slices mentioned in the memoir as containing 'turbid and schillerized' felspars, and there is no doubt about the identity with the peculiarities of the clouded felspars of Ayrshire and elsewhere.

Richey has found that the clouding of the felspars of the gabbros gives to the rocks concerned a remarkable black or bluish-black hue that is very conspicuous in the field (Richey, 1930, p. 238).

There is abundant evidence that clouding is not an original feature of the plagioclase dating from the crystallization period. It is found, for instance, in quartz-dolerites that show other evidence of having been baked, and is not seen in similar rocks that are known to be unaffected by contact-metamorphism (Thomas, 1930, pp. 193, 277, 280). Again in many cases the clouding of gabbro felspars can be definitely ascribed to re-heating due to the later emplacement of a neighbouring intrusion (Richey and Thomas, 1930, pp. 225, 238, 239, 253, 273, 314). In one or two instances the felspar-clouding in the gabbro is recognizable in the field as a localized effect connected with part of the margin of the later intrusion that cuts it. Where the whole of a rock-body shows the phenomenon there is evidence in more than one instance to show that it has been subjected to intense contact-metamorphism by a number of later intrusions in turn (e.g. Richey, 1930, pp. 238, 314).

In a number of cases the available evidence is said to suggest that felspar-clouding in quartz-gabbro and eucrite has been brought about by the permeation of the rock-mass by granophyric material that consolidated partly as mesostasis and partly as veins. In some cases this granophyric material appears to be of external origin, and to have been injected after the shattering of the rock by explosion (Richey and Thomas, 1930, pp. 101, 102, 267, 268). In other cases the granophyric material appears to belong to the rock itself; the clouding would in this case be a deuteric effect (Richey and Thomas, 1930, pp. 101, 102, 278).

In Ardnamurchan, however, it is in many cases impossible to refer the clouding *definitely* to one particular agency. Some of the intrusive masses have been proved to be more or less granulitized by re-

heating although there is no intrusion now exposed at the surface that can reasonably be supposed to have effected that re-heating (e.g. Richey and Thomas, 1930, pp. 280, 281). · Again, in more than one case, the chilled edge of an intrusion has been partly granulitized by re-heating apparently consequent on fresh influx of magma *from the same source* (Richey and Thomas, 1930, pp. 230, 333, 334). In these cases it should be noted that the re-heating is not deduced from the presence of clouded felspars, but from other, or additional, evidence of contact-metamorphism (partial granulitization, &c.).

Under these circumstances the writer does not consider that Ardnamurchan provides *definite* proof that permeation by residual acid magma has produced clouding of plagioclase felspar, though admittedly such may actually be the case: it is, however, quite clear that in many cases clouding has been produced by contact-metamorphism due to a known later member of the plutonic complex. All the evidence is against the plagioclase-clouding being an original feature of the felspar crystallization period.

In discussing the clouded felspars of the gabbroic rocks of Ardnamurchan one cannot pass over Judd's references to them, and the part they played in his 'theory of schillerization' (Judd, 1885, pp. 375–387; 1886, pp. 82, 83; 1889, p. 244). Some of the phenomena exhibited by the basic felspars of the plutonic rocks of Ardnamurchan and elsewhere, that were described by Judd as 'schillerized', are undoubtedly the same as those referred to by the writer as 'clouding' of various types. Judd was of course not fully aware of the diversity of the rock-masses he studied, nor of their complex time-relationships. We shall therefore not analyse his conclusions; nor have we space to follow up the literature of schillerization.

The writer has not been able to come to any conclusion regarding the origin of schiller inclusions in the pyroxenes and olivines of plutonic rocks (gabbros, hyperites, &c.) or of the Scourie dikes. In such rocks clouding of the felspar is frequently accompanied by schillerization of pyroxenes and olivines. But it is also a fact that contact-metamorphism produces clouding in the felspars of lavas and minor intrusions in which ferromagnesian minerals are not schillerized.

The Baltimore gabbro, and Swedish hyperites.

The petrography of the gabbro—gabbro-diorite (massive epidiorite)—hornblende-schist complex of Baltimore, Maryland, U.S.A., presents many points of similarity to that of the Scourie dikes discussed

above. These rocks were described by Williams in 1886. Further work has been published quite recently (Insley, 1928, pp. 289–332; Knopf and Jonas, 1929, pp. 102–137). Williams pointed out the close resemblances between these American gabbroic rocks and the hyperites and allied types of Sweden. He describes and illustrates fine dust-like inclusions in the felspars of both gabbro and gabbro-diorite (Williams, 1886, p. 21 and plates); but, like Insley, Knopf, and Jonas, regards them as original features of the plagioclase. There is no doubt that he was dealing with felspars clouded by inclusions in the same way as those discussed in the present paper. Knopf and Jonas consider the inclusions to be ilmenite or magnetite (1929, p. 110). Williams records too the presence of schiller inclusions in the augite and hypersthene of the gabbro. The hornblendic rocks (gabbro-diorites) are stated to pass laterally into hornblende-schists, perhaps most commonly near the junction of the gabbroic rocks with the adjacent schists and gneisses. Insley, Knopf and Jonas ascribe the alteration of the hypersthene-gabbro to regional dynamic metamorphism.

Törnebohm, in his paper on the Swedish hyperites (1877, pp. 379–393), describes the brownish clouding of the plagioclase felspars, but he regards it as an original feature. He also refers to schiller inclusions in the augite, hypersthene, and olivine. The hyperite is said to be changed into a diorite-like rock (hyperite-diorite), often rich in garnet, both in the neighbourhood of the surrounding rocks and in the vicinity of quartz-veins in the middle of the rock-mass.

From later accounts (Högbom, 1910, p. 30; 1913, p. 18) we learn that the hyperites are lenticular bodies or sills. In their interiors they have original igneous structure well preserved. At their boundaries they pass over into garnetiferous amphibolites, generally with a well-developed schistosity conforming to the foliation of the adjacent gneiss. According to Högbom's 1910 paper the hyperites have been subjected to the high-grade metamorphism, connected with tectonic movements, that produced the neighbouring gneisses. But in his later account (1913) he argues, from the fact that the hyperites have locally retained primary igneous structure, that they are *younger* than the far-reaching metamorphism that has produced the neighbouring gneisses.

From the above accounts it is obvious that both the Baltimore gabbro and the Swedish hyperites have been subjected to metamorphism involving the action of shearing stress. The writer would

suggest that the sequence of events that affected the gabbro and the hyperites is much the same as that postulated at Scourie (p. 530). First thermal metamorphism without shearing stress re-heated the rocks long after their consolidation, and brought about the clouding of their felspars. Later on, under different physico-chemical conditions in which stress and probably circulating water in some form played an important part, the rocks were converted into epidiorites and hornblende-schists. In both America and Sweden the gabbros and hyperites are now known to be cut by granitic intrusions in some localities. The presence *in depth* of the granitic magma-reservoir, from which the acid intrusions were later injected, may have been an important or dominant factor in the first phase of thermal metamorphism without appreciable shearing stress.

Summary and Conclusions.

In the intermediate and inner zones of contact-aureoles thermal metamorphism has often, but not invariably, produced in the fresh plagioclase felspars of lavas and minor intrusions a peculiar and easily recognized type of clouding due to the development of minute inclusions. When, in the highest grades of such contact-metamorphism, original plagioclase crystals have been recrystallized, the newly-formed felspar is unclouded. Clouded phenocrysts have, however, often remained stable although the felspar of the finer-grained groundmass is completely granulitized by recrystallization. This is because, under contact-metamorphic conditions, large fresh crystals are more stable than aggregates of small crystals.

The minute inclusions are very often restricted to the more basic portions of plagioclase crystals, and are absent from the more albite-rich parts. This fact suggests that the original nature of the felspar controls the formation of the inclusions.

There may be some significance in a fact that can be ascertained by looking through a large number of analyses of felspars. A certain amount of iron oxide is a fairly constant feature, but in the series oligoclase-anorthite the percentages are often almost twice as great as most of the higher values recorded in albite or in potash-felspars. It therefore seems possible that the preferential clouding of basic plagioclase is due to its having an original iron-content higher than that of albitic or potassic felspar. In this case the clouding is caused by the appearance of iron oxide as such, or by its concentration to some extent by migration. Clouding due to minute ferromagnesian

particles could be accounted for in a similar way, for some percentage of magnesia is also a feature of felspar analyses.

Partly on the evidence of clouded felspars, the suggestion is made in one section of this paper that certain malchite dikes in the Odenwald, Germany, have been affected by contact-metamorphism.

Observations in Ayrshire and Ardnamurchan have shown that one effect produced in dioritic and gabbroic rocks by a later plutonic intrusion is the development in their plagioclase felspars of a peculiar cloudiness like that found in the contact-metamorphosed lavas and minor intrusions already mentioned.

Clouded felspars are also found in certain gabbros, 'hyperites', and metadolerites known to have undergone regional metamorphism. In a number of such rocks cited above (Scourie, Baltimore, Sweden) the presence of clouded felspars, like those in contact-metamorphosed igneous rocks, has led the writer to postulate a high degree of heating, comparable to that in granitic contact-aureoles, at an early stage in their metamorphism.

The evidence set out above shows that in the case of *any* igneous rock with clouded felspars it seems necessary to prove that such a rock-body can never have been subjected to regional- or contact-thermal metamorphism, before the clouding can be regarded either as an original feature of the felspars, or as a deuteric effect that arose at a late stage in the consolidation period.

Acknowledgements.—The writer acknowledges with gratitude the help so freely given by Professor A. G. Högbom and Dr. Axel Gavelin of Stockholm, and by Professor G. Klemm of Darmstadt, in sending rock specimens or literature, and in giving information based on their personal knowledge of certain districts, and to Mr. J. E. Richey and Dr. H. H. Thomas for their advice regarding the section of this paper dealing with the Tertiary plutonic rocks of Ardnamurchan. The loan of a number of rock-slices from the collections of Edinburgh University has also been of great assistance.

Bibliography.

(An asterisk indicates literature in which clouding of felspars in igneous rocks is shown to be the result of thermal metamorphism.)

1877 Törnebohm (A. E.). Ueber die wichtigeren Diabas- und Gabbro-Gesteine Schwedens. Neues Jahrbuch Min. Geol., pp. 379–393.

1885 Teall (Sir J. J. H.). The metamorphosis of dolerite into hornblende-schist. Quart. Journ. Geol. Soc. London, vol. 41, pp. 133–144.

— Judd (J. W.). On the Tertiary and older peridotites of Scotland. Quart. Journ. Geol. Soc. London, vol. 41, pp. 354–416.

1886 Williams (G. H.). The gabbros and associated hornblende rocks occurring in the neighbourhood of Baltimore, Md. Bull. U.S. Geol. Survey, no. 28.

— Judd (J. W.). On the gabbros, dolerites, and basalts, of Tertiary age, in Scotland and Ireland. Quart. Journ. Geol. Soc. London, vol. 42, pp. 49–89.

1888 Teall (Sir J. J. H.). British Petrography. London.

1889 Judd (J. W.). On statical and dynamical metamorphism. Geol. Mag., n. ser., dec. 3, vol. 6, pp. 243–249.

1899 Teall (Sir J. J. H.). *In* The Silurian rocks of Britain, vol. I, Scotland. Mem. Geol. Survey, Great Britain.

*1901 Kynaston (H.). *In* Summary of Progress for 1900. Mem. Geol. Survey Great Britain, pp. 82–83.

*1905 Kynaston (H.). Notes on contact metamorphism round the Cheviot granite. Trans. Edinburgh Geol. Soc., vol. 8, pp. 18–26. (Read in 1899.)

1907 Teall (Sir J. J. H.). *In* The geological structure of the north-west Highlands of Scotland. Mem. Geol. Survey, Great Britain.

— Rosenbusch (H.). Mikroskopische Physiographie der Mineralien und Gesteine, vol. 2, pt. 1, Stuttgart.

1910 Högbom (A. G.). Precambrian geology of Sweden. Bull. Geol. Inst. Upsala, vol. 10, pp. 1–80.

1913 Högbom (A. G.). Fennoskandia. Handbuch der Regionalen Geologie, vol. 4, no. 3.

*1916 Bailey (E. B.). *In* The geology of Ben Nevis and Glen Coe. Mem. Geol. Survey, Scotland.

— Tyrrell (G. W.). A contribution to the petrography of Benguella, based on a rock collection made by Prof. J. W. Gregory. Trans. Roy. Soc. Edinburgh, vol. 51 pp. 537–559.

1918 Teall (Sir J. J. H.). Dynamic metamorphism. A review, mainly personal. Proc. Geol. Assoc. London, vol. 29, pp. 1–15.

1921 Tilley (C. E.). The granite-gneisses of southern Eyre Peninsula (South Australia) and their associated amphibolites. Quart. Journ. Geol. Soc. London, vol. 77, pp. 75–131.

1924 Thomas (H. H.) and Bailey (E. B.). *In* The Tertiary and post-Tertiary geology of Mull, Loch Aline, and Oban. Mem. Geol. Survey, Scotland.

1928 Insley (H.). The gabbros and associated intrusive rocks of Harford County, Maryland. Maryland Geol. Survey, vol. 12, pp. 289–332.

1929 MacGregor (A. G.). Metamorphism around the Lochnagar granite, Aberdeenshire. Rep. British Assoc. Glasgow, 1928, Sect. C, Geology, pp. 553–554.

— Knopf (E. B.) and Jonas (A. I.). The geology of the crystalline rocks of Baltimore County. *In* Baltimore County. Maryland Geol. Survey, pp. 97–199.

*1930 MacGregor (A. G.). *In* The geology of north Ayrshire. Mem. Geol. Survey, Scotland.

*1930 Richey (J. E.) and Thomas (H. H.). *In* The geology of Ardnamurchan, north-west Mull, and Coll. Mem. Geol. Survey, Scotland.

MINERALOGICAL SOCIETY PUBLICATIONS

The Publisher is Mr. Humphrey Milford, Oxford University Press, *Amen House, Warwick Square, London, E.C.* 4.

Mineralogical Magazine.—Current Numbers price 6*s.* net each. Annual Subscription for four Numbers post free 20*s.*, payable in advance to the Publisher, either direct or through any bookseller.

Back Numbers.—With the exception of Nos. 17, 18, 19, 21, and 22, which are out of print (and some few numbers of which the stock is low and which are reserved for the sets mentioned below), all numbers can be supplied separately at the following net rates: Nos. 1–48 at 4*s.* each; Nos. 49–111 at 5*s.* each; Nos. 112 (1926) onwards at 6*s.* each. Since 1920 (Vol. XIX) the Numbers have been issued quarterly, and include a separately-paged appendix of *Mineralogical Abstracts.*

Geological Map of the Shetland Islands (separate from Vol. II). Price, 4*s.* mounted, 2*s.* 6*d.* unmounted, net.

General Index to Vols. I–X, 4*s.*; to Vols. XI–XX, 6*s.* net.

Mineralogical Abstracts (Vol. I, Nos. 1–12, 1920–22, issued with Vol. XIX of the Magazine) are also sold separately. Price 2*s.* 6*d.* net each number. Later numbers (Vol. II, 1923–25; Vol. III, 1926–28; Vol. IV, 1929–) are issued only as part of the Magazine.

Bye-Laws and List of Members (1929). Price 1*s.* net.

Part sets at the following reduced rates. Set A.—Vols. I–X (Nos. 1–48, 1876–94, and Index No.) at 4*s.* per number less 15% (to Members of the Society less 35%). Set B.—Vols. XI–XX (Nos. 49–111, 1895–1925, and Index No.) at 5*s.* per number less 15% (to Members less 35%). Set C.—Vols. I–XX (Nos. 1–111 and two Index Nos.) at the above initial prices less 20% (to Members less 40%).

Proceedings of the Crystallological Society [amalgamated with the Mineralogical Society in 1883]. Parts I and II (1877, 1882), price 4*s.* net each.

GENERAL NOTICES

Members desiring to propose Candidates for Election are requested to send the names and qualifications of the Candidates to the General Secretary, Mr. W. Campbell Smith, *British Museum of Natural History, South Kensington, London, S.W.* 7. There is an entrance fee of one guinea and the annual subscription is one guinea; the latter can be compounded for by a single payment of fifteen guineas. New Members, on the payment of their first subscription, receive all the numbers of the Magazine for the year for which the subscription is paid.

There are four meetings of the Society each year, on Tuesdays at 5.30 p.m. in January, March, June, and November. They are held (by kind permission) in the Apartments of the Geological Society, Burlington House, Piccadilly, London, W. 1. Titles of papers to be read at these meetings, with a view to subsequent publication in the Magazine, should be sent to the General Secretary at least two weeks before the meeting. Authors alone are responsible for the views set forth in their respective papers. They are allowed, free of charge, fifty separate copies of their papers published in the Magazine.

MINERALOGICAL MAGAZINE

CONTENTS OF NO. 133

(June, 1931)

PAGE

D. R. GRANTHAM and F. OATES: The Mbosi meteoric iron, Tanganyika Territory. (With Plates XIX and XX) . 487

S. R. NOCKOLDS: The Dhoon (Isle of Man) granite: a study in contamination 494

M. H. HEY: On pink epsomites and fauserite 510

A. J. P. MARTIN: On a new method of detecting pyro-electricity 519

A. G. MACGREGOR: Clouded felspars and thermal metamorphism 524

MINERALOGICAL ABSTRACTS

(Vol. 4, No. 10, Pages 433–480)

Notices of Books (p. 433).—Mathematical Crystallography (p. 439).—Crystal-optics (p. 442).—Physical Properties (p. 450).—X-rays and Crystal-structure (p. 458).—Topographical Mineralogy (p. 468).—Miscellaneous (p. 478).

	PAGE		PAGE		PAGE		PAGE
AHNERT, E. E.	474	FREISE, F. W.	453	MASUDA, M.	454	SCHLOSSMACHER, K.	444
ALEXANDER, E.	479	GALLITELLI, P.	470	MAUGUIN, C.	465	SCHNEIDER, W.	457
ALLSOPP, C. B.	448	GAUDEFROY, C.	442–3	MEHL, E.	466	SCHNEIDERHÖHN, H.	434
ALOISI, P.	443	GEBHARDT, T.	439	MEHMEL, M.	462	SCHWARTZ, G. M.	477
AMINOFF, G.	461, 469	GEFFCKEN, W.	448	MELLE, F. A. VAN	463	SCHWIETRING, F.	447
ANTAL, J.	480	GINGOLD, J.	455	MELMORE, S.	479	SCRIVENOR, J. B.	474
AUBEL, R. VAN	476	GIUSCÁ, D.	473	MENZER, G.	461	SHUBNIKOV, A.	453
AUBERT DE LA RUE, E.	477	GOLDSCHMIDT, V.	439	MIDDLEMISS, C. S.	474	SNOW, C. P.	446
BADYAL, L. R.	474	GOSSNER, B.	461–2	MILLOSEVICH, F.	478	STEWART, D.	477
BARTH, T.	449	GOUGH, H. J.	452	MODELL, D. I.	463, 479	SWAMINATHAN, V. S.	473
BEBIANO, J. B.	476	GYULAI, Z.	455	MÖLLER, H.	460	TAKANÉ, K.	454
BECKENKAMP, J.	441	HALLA, F.	466	MONTANARO, E.	471	TAMMANN, G.	450
BERG, G.	433	HARANG, L.	461	MOTZOK, D.	440	TARR, W. A.	438
BERGER, W.	446	HARTLY, D.	455	MOUNTAIN, E. D.	443, 475	TCHIRVINSKY, P.	480
BERMAN, H.	449	HENGSTENBERG, J.	467	MÜGGE, O.	453	TERTSCHE, H.	453
BIANCHI, A.	469	HETTICH, A.	456	MUSSGNUG, F.	462	THOREAU, J.	478
BLANK, F.	452	HEVESY, G.	479	NÁRAY-SZABÓ, S.	462	TOKODY, L.	451
BORGSTRÖM, L. H.	449	HEWETT, D. F.	479	NIGGLI, P.	441	TORGASHEFF, B. P.	474
BORMUTH, C.	445	HEYWORTH, D.	461	OBREIMOFF, J. W.	453	TRAUTZ, O. R.	462
BRAEKKEN, H.	460–1	HUNT, W. F.	437	O'HARRA, C. C.	477	TUČAN, F.	478
BRAGG, W. L.	466	ITO, T.	440	ORCEL, J.	444	UEDA, J.	454–5
BRILL, R.	459	JACKSON, W. W.	467	PALACHE, C.	479	VOELLMY, H.	447
BROOMÉ, B.	461	JAEGER, F. M.	463	PARKER, R. L.	442	VOSKUIL, W. H.	437
BROWN, R.	468	JENCKEL, E.	450	PARSONS, A. L.	445	WARREN, B. E.	462–3, 466
BRÜCK, H.	454	JENKIN, A. K. H.	468	PATTERSON, A. L.	458	WASHINGTON, H. S.	436
BUERGER, M. J.	450–1	JEŽEWSKI, M.	456	PAULING, L.	464–5	WASSERMANN, G.	451
CAROBBI, G.	480	KLÜBER, H.	433	PEACOCK, M. A.	439	WATSON, T. L.	438
CAVINATO, A.	469	KOCH, S.	472, 480	PORTER, M. W.	446	WEST, J.	467
CHIRVINSKY, P. N.	480	KOHNER, H.	448	RABI, I. I.	458	WESTENBRINK, H. G. K.	463
CHUDOBA, K.	442	KOTOH, N.	460	RAMDOHR, P.	434	WEVER, F.	460
CLOUSE, J. H.	462	KÔZU, S.	454–5	RANDALL, J. T.	459	WHERRY, E. T.	440
COHN, W. M.	460	KRAUS, E. H.	437	REINHARD, M.	435	WRIGHT, F. E.	443
CONNOLLY, J. P.	477	KRENNER, J.	471	RIES, H.	437–8	WÜRSTLIN, K.	479
COOPER, B. S.	459	KUHN, R.	467	RINNE, F.	446	WYCKOFF, R. W. G.	467
COX, H. L.	452	LANDES, K. K.	450	RODOLICO, F.	473	ZIMÁNYI, K.	471
D'ACHIARDI, G.	478	LAVES, F.	440–1	ROOKSBY, H. P.	459		
DUNBAR, C.	462	LENNARD-JONES, J. E.	459	RÖSCH, S.	446		
EHRINGHAUS, A.	445	LEONHARDT, J.	440	ROVE, O. N.	479		
FABER, W.	446–7	LOWRY, T. M.	446, 448	SACHS, G.	459		
FARNHAM, C. M.	435	MACHATSCHKI, F.	462, 480	SANDER, B.	459		
FISK, H. G.	449	MANCHESTER, J. G.	476	SCHAEFER, C.	445		
FOEX, G.	458	MARSHALL, C. E.	456	SCHLEEDE, A.	456		
FORREST, J.	457						

First printed in Great Britain, at the University Press, Oxford

Reprinted by photo-litho by Alden & Mowbray Ltd,

at the Alden Press, Oxford, 1970